The sources of growth in a technologically progressive economy: the United States, 1899-1941

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Abstract

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The Sources of Growth in a Technologically Progressive Economy: the United States, 1899-1941[1]

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We develop new aggregate TFP growth estimates for the United States between 1899 and 1941, and sectoral estimates at the most disaggregated level so far, 38 industries. We include hard-to-measure services, and a refined measure of sectoral labour quality growth. The resulting dataset supersedes Kendrick (1961), showing TFP growth lower than previously thought, broadly based across industries, and strongly variant intertemporally. The four 'great inventions' that Gordon (2016) highlighted were important but less dominant in TFP growth than their predecessors in the British Industrial revolution. The findings also make it unlikely the 1930s had the twentieth century's highest TFP growth.

Technological change is the ultimate source of sustained productivity growth and thus of long-run increases in living standards. Economic growth can come from using additional labour or capital inputs, or from using these inputs more effectively – which constitutes technological change. In a conventional neoclassical growth model, this technological change is represented by total factor productivity (TFP) growth. Since the amount of labour and capital that can be added has limits, growth in TFP is key to long-run growth. For output growth projections, the future TFP growth rate is fundamental. The recent U.S. productivity slowdown has largely been driven by a significant decline in TFP growth. Antolin-Diaz et al. (2017) estimate that business sector trend TFP growth has decreased from 1.6% per year in the late 1990s to 0.4% in 2015. Many econometricians see this fall as likely to persist.

Technological 'pessimists' like Robert Gordon believe that 0.4% per year is a good prediction of future TFP growth (2016, p. 568). Gordon argues that rapid TFP growth in the mid-20th century U.S. was driven by four 'great inventions' and that nothing similar is foreseeable today. Nicholas Bloom et al. (2017) emphasize that since the 1930s the productivity of R&D employment has declined significantly as 'ideas get harder to find'. These authors point out that the ratio of TFP growth over effective researchers fell by 5.3% annually between 1930-2015. An informed view on the sources of TFP growth during the early 20th century is one key ingredient to evaluate whether 'great inventions' dominate and whether rapid TFP growth reflects the impact of R&D.

During the second industrial revolution, the United States overtook Britain as the world's leading economy and achieved unprecedented rates of TFP growth. Partly based on John Kendrick's estimates,[2] Solow's (1957) growth accounting produced one of the most famous discoveries in growth economics, namely that 7/8th of U.S. labour productivity growth during 1909-1949 came from technical change. It could not be attributed to capital deepening but was a residual. As Gordon stressed, American economic growth leapt forward. During the early twentieth century, the United States was at the forefront of the important new technological developments such as aviation, the internal combustion engine, mass production, electricity, and petrochemicals (Mowery and Rosenberg, 2000). Electricity, its impact peaking in the 1920s (David, 1991), is widely recognized as one of history's most significant general-purpose technologies (GPTs). Notably, TFP growth continued to be rapid through the Great Depression. Field (2003) labelled the 1930s as the 'most technologically progressive decade' of the twentieth century.

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[2] See, for example, Kendrick (1956).

Against this background, the main contribution of this paper is to provide a consistent growth account, taking into account changes in hours worked and available capital stock, as well as controlling for the heterogeneity across workers and different types of capital. This allows us, for the first time, to compare the technological progress achieved in post-war America to that realized between 1899-1941, while using the same labour quality methodology. To achieve a full understanding of the sources behind this growth, we break aggregate U.S. TFP growth down into the contributions of 38 sectors consistent with the detailed sectoral level reported after World War II. We thus develop new insights into the origins and the process of American productivity growth in the early twentieth century.

Our analytic narrative supersedes Kendrick (1961), the main source available until now. We develop much better estimates which provide a more complete description of the sectoral pattern of TFP growth across the American economy. To achieve this, we have improved and extended Kendrick's estimates in five ways. First, our growth accounting covers in detail about 80% of the private domestic economy (PDE), compared with 50% in Kendrick's estimates. Second, we adjust TFP growth for intra-occupational labour quality improvements. Third, we estimate the capital input contribution on a capital-services basis where feasible (i.e., 1929-1941). Fourth, we provide detailed estimates for 1929-1941 rather than 1929-1937. Fifth, we obtain a set of value-added weights which underpin the measurement of sectoral contributions to total TFP growth. We use the results of the above to investigate and qualify claims made by Solow (1957), Field (2011) and Gordon (2016).

To this end, we address three issues. First, we re-examine the rate of TFP growth in the PDE prior to 1941, which allows us to review its contribution to labour productivity growth. Second, we re-consider whether the 1930s really was the most technologically progressive decade of the twentieth century. Third, we quantify the impact of the technology clusters that are said to comprise the 'great inventions', both with and without TFP spillovers.

Our approach is as follows. We use conventional neoclassical growth accounting assumptions, starting with Kendrick (1961) for 1899-1929 and improving and extending them where possible. We are able to add 5 sectors: Construction, Distribution, Finance, insurance, and real estate (FIRE), Postal services, and Spectator entertainment. We produce estimates for 1929-1941 using the National Income and Product Accounts (NIPA) to obtain nominal value added at the industry level (deflated using available price data) as well as hours worked. Capital inputs for 1929-1941 were constructed using a perpetual inventory method and investment data from the U.S. Bureau of Economic Analysis' (2010) fixed assets tables. The capital stocks were then aggregated to the industry level, based on imputed rental prices. The result is a measure of capital services that accurately captures the input flows derived from the capital in place. We replace Kendrick's pre-1929 labour input indices and develop new industry level indices for 1929-1941, taking into account labour quality changes. The advantage of our method compared with that of Kendrick (1961) is that it accounts for increases in educational attainment within occupations. Since we now have both capital and labour inputs measured on a similar basis as the Bureau of Labor Statistics (BLS), our TFP estimates for 1929-1941 are comparable with the post-1948 BLS estimates.

We use these newly constructed sectoral estimates to examine the concentration and persistence of the industry origins of TFP growth. For each sector, we investigate both TFP growth and the intensive growth contribution (IGC), which is TFP growth multiplied by share of total value added. To also estimate cross-sector TFP spillovers we develop a regression analysis similar to David (1991), using our new data. This permits an estimate of the great inventions' importance for TFP growth that includes spillovers.

These analyses result in four key findings that differ from those of earlier works. We discuss these in turn. First, we find much higher labour quality growth than Kendrick (1961): for 1899-1941 about 0.8% per year, while Kendrick's estimate was about 0.3%. Consequently, we estimate a lower TFP growth rate in the PDE at 1.3% per year during 1899-1941, compared with Kendrick's estimate of 1.7%. Accordingly, TFP growth accounted for 60% of labour productivity growth rather than the 7/8th proportion Solow (1957) found.

Second, we estimate that aggregate (PDE) TFP growth was 1.86% per year during 1929-41, compared with 1.98% during 1948-60 and 2.21% during 1960-73. This suggests that the 1930s may well not have been the most technologically progressive decade, as Field (2003) argued. This finding should be treated with some caution, as our detailed discussion in section 4 makes clear.

Third, we estimate that the technology clusters associated with Gordon's 'great inventions' accounted for just under 40% of aggregate TFP growth during 1899-1941. Their contribution rose steadily from about 0.3 percentage points per year in 1899-1909 to just over 0.8 in 1929-41. This is impressive but possibly less overwhelming than a reader of Gordon (2016) might imagine. We find that TFP-growth originated in a far wider variety of sectors and that big unglamorous sectors like Construction, Farming, and Foods sometimes had a substantial impact on growth. Including TFP spillover effects, we find that the 'great inventions' could have accounted for 55% of TFP growth in the 1930s.

Fourth and finally, our estimates of sectoral TFP growth contributions show that early 20th century TFP growth was much more broadly based than during the first industrial revolution, which had been dominated by a few modernized sectors. Our estimates also show that sectoral TFP growth contributions were not dominated by the relatively few sectors with the vast majority of R&D inputs. We certainly do not argue that there is no relationship between R&D and productivity growth. The productivity of R&D may well have declined between 1930-2015, as Bloom et al. (2017) suggest. Yet, using the ratio of TFP growth to R&D inputs to compare researchers' productivity in the 1930s and today is likely to exaggerate the rate at which ideas supposedly have been getting harder to find.

1. Existing evidence on the sources of American productivity growth

Up to now, studies of long-run American productivity growth have been hampered by the lack of readily available data on output growth, capital formation, skill formation and technological change for the first half of the twentieth century. The comparison between the pre- and post-war periods suffers from discrepancies in definitions and methods used to estimate the growth in total factor inputs. It must somehow deal with substantial differences in coverage and detail of industries underlying PDE growth. Only with industry-level data can we accurately analyse the longitudinal effect of long-run waves of innovation and TFP growth, such as the 'great leap forward' hypothesized by Field (2011), or the contribution of the great inventions stressed by Gordon (2016).[3] Similarly, only with consistent industry-level measures of the change in output, employment, hours worked, labour quality, stocks and capital composition, can we assess the contribution of technological change to the American economy's productive capacity prior to the Second World War.

[3] Gordon (the 1940s) and Field (the 1930s) disagree on the period when TFP growth was at its maximum but this debate is outside the scope of our research.

First, we review previous attempts to harmonize TFP growth measures for the (long) twentieth century, focusing on labour quality estimation. Labour quality either played a major or only a marginal role in the rapid growth of the American economy's productive capacity, depending on the study one consults. Second, we discuss existing estimates of sectoral TFP growth contributions, which have been limited by a lack of detail in the productivity growth breakdown, as well as by inconsistent measures of technological change over the last century. Third, we discuss the literature on technological spillovers during the second industrial revolution. This has hitherto suffered from incomplete or sub-optimally constructed industry-level productivity data.

Since Solow (1957), scholars have made important contributions to his growth accounting framework, helping to identify the sources of growth in the United States in the first half of the twentieth century. A common theme is to incorporate an estimate of the contribution made by labour quality improvements, to labour productivity growth, which was not considered by Solow. This will downsize somewhat the importance of TFP growth. However, the methods used vary and none of them has proven to be entirely satisfactory.

Kendrick's (1961) major research project adjusted labour input to capture changes in the composition of employment based on occupational wage differentials. This allowed a labour quality component to be added to person-hours growth. For the period Solow (1957) investigated, the PDE in 1909-49, this resulted in labour quality growth of 0.31% per year, which reduced the TFP contribution to labour productivity growth from 88% to 78%. Unfortunately, this procedure leaves out the impact of improved labour quality *within* occupations. This is potentially a serious omission, as these decades saw large increases in educational attainment (Goldin and Katz, 2008).

The next milestone was Denison's (1962) work, extended in a series of volumes culminating in Denison (1985). Denison gave great weight to the labour quality issue and made quite elaborate estimates of its rate of improvement. Yet his work is not consistent with the current BLS approach. It is undermined by relying on assumptions not generally regarded as acceptable. The work's strengths included a serious attempt to capture education's impact on labour quality, using estimates of educational attainment and associated wage differentials. The weaknesses included an arbitrary assumption to discount 40% of these differentials as due to intrinsic ability; unwarranted adjustments for the impact of changing working hours on productivity; and, finally, a failure to deal adequately with employment shifts between industries.

Denison's original estimates showed a large labour quality contribution, estimated to have increased by 1.06% per year during 1913-1950. If used to correct Kendrick's TFP estimates this implies a revision to 54% of labour productivity growth (Gordon, 2000). However, Denison's estimates can be made more nearly comparable with the BLS methodology by removing the ability correction and the hours effect on productivity. Doing this results in labour quality growth over 1913-1950 giving a corrected TFP contribution of 75% of labour productivity growth (Gordon, 2000). A similar approach was adopted by Abramovitz and David (2001), who found that TFP corrected for labour quality accounted for 67% and 77% of PDE labour productivity growth during 1905-27 and 1929-48. Nevertheless, these would all be incomplete calculations because they lack a proper accounting for inter-industry occupational change, and so do not capture a vital part of labour quality change.

Gordon (2000) also proposed adjustments to Kendrick's capital input estimates, first to make them more comparable with modern methods, and second to deal with various biases in official statistics. The latter notably concerned assumed asset lifetimes during the 1940s and 1950s and government capital formation during World War II. Gordon proposed a correction to capital stock estimates based on asset-price weighting to approximate rental-price weighting. In effect, this significantly increased the equipment weighting relative to structures and moved closer to estimating capital-services based capital inputs. All Gordon's (2000) adjustments together, both to capital and labour inputs, produce a TFP growth estimate of 1.00% per year during 1913-1950, or 56% of labour-productivity growth. However, as we discuss in section 4, this treatment of capital inputs rests on assumptions which are somewhat problematic.

Gordon (2016) puts forward a much-revised view of TFP growth's role in the American economy during the long twentieth century. He modifies his earlier work primarily by adopting modern NIPA estimates of real output, based on chain-linking the price deflator. In addition, his labour quality estimate now drops a modified Denison approach in favour of using an educational attainment index based on Goldin and Katz (2008). The key message is that the high-TFP-growth era, which was yet to run its course when Solow (1957) wrote, was transient. For the halcyon period 1920-1970, Gordon's new estimates are that TFP growth averaged 1.89% per year, or 67% of labour productivity growth. In contrast, for 1890-1920 TFP grew at just 0.46% per year and for 1970-2014 at 0.64%, comprising only 31% and 40% of labour productivity growth, respectively. However, the new real output measures may not be an improvement for the 1930s and 1940s (see section 4).

Field (2003) examined TFP growth in the PNE in the 1930s. He concluded that this was the most technologically progressive decade of the twentieth century. This finding was based on the Kendrick database for 1929-1941, whereas Kendrick himself (1961) used 1929-1937 when comparing sub-periods. Field argued, reasonably enough, that 1941 was less affected by problems of capacity under-utilization in the recovery from the depression. Field (2003) did not attempt to correct Kendrick's flawed labour quality estimates, however, resulting in an upward bias to its TFP growth estimates. Denison (1985) estimated much higher labour quality growth and found that TFP growth in 1929-41 was less than half that of 1948-73. Abramovitz and David (2001) and Gordon (2000), did not report TFP growth for 1929-41, but took the 1930s and 1940s as one interval. They found that TFP growth was somewhat lower than in the 1950s and early 1960s. In later work, Field (2011; 2013) increased the 1930s TFP growth estimate further, by making a 'cyclical adjustment'. This was to address what he saw as a problem of still incomplete recovery in 1941.

What are the key takeaways for this paper from this rather bewildering array of results? First, it is generally agreed that TFP growth contributed less to labour productivity growth in the first half of the twentieth century than Solow (1957) thought. Depending on the chosen period and method, a range of 2/3 to 3/4 rather than 7/8 is a reasonable summary of recent estimates. Second, although taking full account of labour quality growth is recognized as centrally important, no study has yet provided a comprehensive estimate embracing both educational improvements within occupations and occupational shifts. Accordingly, it seems likely that labour quality matters more than current studies allow. Third, it is desirable, if possible, to put capital input estimates on a capital-services basis, but this has yet to be attempted for the pre-World War II period. This adjustment is expected to reduce estimated TFP growth even further.

Kendrick (1961) estimated TFP growth for 33 industries, for the aggregate of these sectors, and for the PDE (including the rest of the economy treated as a residual). Yet he did not offer estimates of sectoral intensive growth contributions, nor a set of value-added weights by industry, with which to calculate these contributions. Field (2006, 2011) made a significant advance by estimating the intensive growth contribution of 4 broad sectors (manufacturing, wholesale and retail trade, transport and utilities, and other) in 1919-29 and 1929-41 using value-added weights. He also further sub-divided the contribution of transport and utilities into 8 sub-sectors for 1929-41. This enabled him to highlight the dominance of manufacturing in the 1920s and contrast it with much more broadly-based TFP growth in the 1930s, when the distribution sector played a prominent part. More can be learnt by disaggregating further, using a fuller set of value-added weights and TFP growth estimates at the industry level that take account of labour quality growth. This can provide the basis for a detailed, 38-sector look at the TFP growth contribution made by sectors which benefited from the great inventions.

Gordon (2000; 2016) has stressed the fundamental importance of the great inventions of the late nineteenth and early twentieth centuries to the surge in TFP growth from the 1920s through the 1960s. He argues the surge was driven by four technology clusters: electricity; the internal combustion engine together with derivative inventions such as interstate highways and supermarkets; rearranging molecules (chemicals and pharmaceuticals); and, finally, the entertainment, communication and information sector. However, Gordon has not attempted to quantify the growth contribution of these four technologies over time. The great inventions obviously made a significant contribution to productivity advance. Nevertheless, it is reasonable to suppose that the United States had characteristics potentially conducive to many sources of TFP growth across much or all of the economy. While important, the great inventions may not have been dominant.[4]

The method most commonly used to attribute sectoral TFP growth contributions across sectors uses own-sector value added weights. With (unremunerated) TFP spillovers, this may not be appropriate. The literature on ICT has tended to look for spillovers within sectors (Basu and Fernald, 2007; Stiroh, 2002), which is unproblematic for conventional sectoral accounting. With inter-sectoral spillovers, the originating sector receives too little and the receiving sector too much credit. Identifying spillovers leads to a redistribution of TFP growth contributions across sectors. It does not lead to an increase in total TFP growth. In the case of electricity in the early twentieth century, Warren Devine (1983) itemized reasons why TFP spillovers might flow from factory redesign. This was facilitated by the shift to electric unit drive machinery, including enhanced configuration flexibility, materials handling, feasibility of single-story plants, and lighter factory buildings, all of which were capital-saving.

In summary, we need a detailed industry breakdown of TFP-growth and an aggregate TFP-growth estimate net of all labour quality growth, comparable with post-war estimates, to understand the role and magnitude of TFP spillovers, to quantify the great inventions' impact, and to provide a better measure of TFP growth during the long 1930s. In what follows, we address these issues.

2. Data and Methods

The definitive study on American productivity growth at the industry level for the first half of the twentieth century is still Kendrick (1961). Although Kendrick offered substantial detail, his estimates fall some way short of what is required for a full empirical assessment of the impact of great inventions, of their spillovers, and of the great depression. Kendrick provides average annual TFP growth estimates for 1899-1953 and sub-periods, for the PDE, and for five sub-sectors which in turn are divided into 33

[4] We examine the criterion for dominance below (Section 5).

industries, covering 54% of the PDE in 1953. The remaining 46% included Construction, Distribution, Finance, and most other services. TFP growth for these sectors was obtained as a residual by comparing the covered sectors' total with the whole economy estimates. For 1899-1953, covered sectors' TFP growth was estimated at 2.1% per year, the PDE's at 1.7%, and the residual sector at 1.3% (Kendrick, 1961, p. 137).

Kendrick's TFP growth concept (*A*) is based on real value-added growth (*Y*) minus the factor-share weighted sum of capital (*K*) and labour input (*L*) growth rates:

$$\hat{A} = \hat{Y} - \alpha\hat{K} - (1-\alpha)\hat{L} \tag{1}$$

Where hats indicate growth rates in natural logarithms and α is the capital compensation share in value added. For the PDE and the five main sectors, labour inputs are based on person-hours weighted by average hourly earnings, to capture labour quality increases that result from workers' movement between differently-paid occupations and industries. Within sub-sectors, however, labour quality is assumed to remain unchanged. Kendrick reports TFP growth rates by sector and sub-sector but does not provide nominal value-added estimates.

We take Kendrick's study as a starting point but extend and improve upon his work. First, we provide TFP growth estimates for a more complete set of industries, reducing the residual sector's size. Second, we provide a full set of value added weights and productivity growth contributions at the industry level. Third, we construct estimates for 1929-41 rather than 1929-37, to address the issues raised by Field (2011). Finally, we take fuller account of labour quality by allowing for the impact of the rapidly increasing educational attainment in the first half of the twentieth century. We estimate labour quality by industry.

We also included five hard-to-measure sectors: Construction, Wholesale and retail distribution, FIRE, Spectator entertainment, and Postal services. For these sectors we estimated capital, labour, factor income shares and output for five benchmark years using a variety of sources, including censuses, the *National Income and Product Accounts* (NIPA) and other secondary sources. For the new, as well as Kendrick's original 33 industries, we calculated TFP growth rates. We also derived the average value-added share in the PDE for all periods. We multiplied these shares by each industry's TFP-growth to obtain each sector's intensive growth contribution (IGC) to PDE TFP growth (see Appendices A and B). Kendrick (1961) did not provide contributions of individual industries to aggregate TFP growth. By doing so, we obtain new insights into the growth process underpinning the pre-war economy.

Next, we developed industry-level estimates extending Kendrick's estimates for 1929-37 through 1941. Real output was estimated using NIPA's industry-level nominal-value-added series, deflated with BLS wholesale prices, production prices from *Historical Statistics of the United States* (Carter et al., 2006), and relevant NIPA price indices for some service sectors. Labour inputs were based on *Historical Statistics* and NIPA for employment, adjusted for hours worked using Kendrick (1961) and on IPUMS (Ruggles et al, 2010) for quality, using the method detailed below. Capital inputs were estimated using capital services. We calculated industry-level capital stocks for the PDE between 1929-1941 by using a Perpetual Inventory Method (PIM) and the investment and depreciation series from the *Fixed Assets* tables of the U.S. Bureau of Economic Analysis. Rental prices of assets by industry reflect the imputed industry rate of return, the asset-specific depreciation rate, and capital gains and losses from changing asset prices. This enables calculation of 'capital compensation' weights to aggregate the capital inputs

(Appendix C).[5]

Two features of our methods deserve some comment: how industrial contributions to aggregate TFP growth are calculated and how we measure labour quality.

Following Kendrick (1961), we employ a growth accounting technique based on value added rather than gross output. This also mirrors the approaches adopted by Field (2011) and Harberger (1998). We multiply TFP growth in industry *j* (A_j), by the average value-added share in the PDE (ω_j). We then sum these contributions of all *n* industries to obtain aggregate PDE TFP growth:

$$\hat{A}_{pde} = \sum_{j=1}^{n} \bar{\omega}_j \hat{A}_j \tag{2}$$

This can be interpreted as measuring an industry's capacity to contribute to economy-wide productivity, i.e. its IGC. An industry's IGC therefore depends not only on its TFP growth, but also on its size. The components of the aggregate, however, are not an accurate measure of disembodied technical change (OECD, 2001).

Our approach to measuring labour quality improves on Kendrick's in three ways. First, it takes account of the implications of the rapid increase in years of schooling for the quality of workers in each occupation over time. Second, it allows for changes in gender composition and work experience. Finally, it permits labour quality measurement at the industry level.

To construct an index of labour input (*L*) for each industry, we assume that labour input for industry *j* be expressed as a translog function of its individual components. We form labour input indices from data on hourly employment by industry (*H*), cross-classified by gender, age and education. Dropping the industry subscript for ease of notation, labour input growth for industry *j* is represented as:

$$\hat{L} = \sum_{l=1}^{q} \bar{\mu}_l \hat{H}_l \tag{3}$$

Where H_l is total hours of work at the industry level for a given set of *q* characteristics of the labour force *l* (gender, age and education), and $\bar{\mu}_l$ the two-period average of this employment group's share in total labour income at the industry level. The share of labour income (μ_l) is the product of the average hourly wage (p_l) and total hours (H_l) for labour characteristic *l,* divided by the total wage sum. Our measure of industry labour quality growth is the difference between the growth rates of the compensation-weighted index of labour input and total hours worked.

We follow a three-tiered approach to the data preparation for the labour quality estimation. First, we estimate individual workers' educational attainment for the pre-1940 census samples, based on the 1940 returns. Second, we construct an employment matrix for 1899-1941 that groups workers according to their predicted educational attainment, gender, age and industry. Last, we derive the compensation matrix based on average wages for each labour category, taken from the 1940 census of population (Appendix D).

Equation (2) considers only an industry's TFP growth contribution's direct effect. There could, however,

[5] It is not possible to use this method pre-1929 because we lack asset-by-industry capital stocks. The differences in TFP growth between the two methods, however, are generally fairly small; the implications are explored in Appendix C.

exist indirect effects through TFP spillovers. David (1991) argued this for electricity's impact on American manufacturing in the 1920s. Gordon's notion of 'great inventions' as technology clusters also seems to encompass TFP spillovers. One could, therefore, take account of spillovers when estimating the 'great inventions' impact. This would amount to a redistribution of the IGC across sectors, rather than raising aggregate TFP growth in the PDE. However, no generally agreed method exists for measuring TFP spillovers. We use an approach similar to David's (1991) but realize that the results need to be treated with caution.

To capture electricity's TFP spillovers, we use an OLS regression to estimate the effect of the growth of electrical motors per hour worked on the TFP growth acceleration relative to the previous period for all manufacturing industries for 1919-29 and 1929-41. To explore the full extent of TFP spillovers from great inventions, we estimate the effect of the growth in capital services from electrical equipment, electrical instruments and transportation equipment on TFP growth acceleration. Here we do not just expand the coverage of capital assets that are likely to embody the great inventions. Capital services also provide a better measure of the output growth contribution of these capital assets (Appendix C). We run the capital services regression twice, for all industries in the PDE (our full sample) and for manufacturing. Systematic capital services data is only available from 1929, so here we can only estimate spillovers during 1929-41. The TFP growth acceleration is the difference between TFP growth in the current and previous period. Following David (1991), we proxied electricity capital growth during the 1920s by growth of installed horse powers of secondary motors in use from the Censuses of Manufacturing, as reported in DuBoff (1979). We based the great inventions' capital services on the BEA's Detailed Fixed Assets tables' investment figures and on methods described in Appendix C.[6]

3. Results

This section reports our industry-level estimates of value added weights, growth of labour quality and TFP, together with the derived estimates of intensive growth contributions, i.e. the sectoral decomposition of TFP growth. We also point out some noteworthy features of these data.

For the PDE, Table 1 shows the revised breakdown of hourly labour productivity growth. In Kendrick (1961), of the 2.16% annual growth between 1899-1941, 13% of the total (0.28 percentage points per annum) was attributed to the growth of capital inputs per hour worked, 10% to labour quality growth (i.e. labour composition), and as much as 77% to TFP growth. The revisions we propose will be discussed in detail below. They lead to a very different breakdown of the sources of labour productivity growth: 14% of it is attributed to capital input growth, as much as 26% to labour quality growth, and 'only' 60% to TFP growth. This shows that Solow's claim that 7/8th of productivity growth in this era was caused by TFP-growth is a significant overestimate of the contribution of the residual.

Value added weights are reported in Table A1 (Appendix A). The relatively large sectors of Wholesale & retail trade and Finance, insurance and real estate (FIRE) – for which we have TFP estimates, but Kendrick did not – contributed nearly as much to the PDE as the entire manufacturing sector. The importance of TFP advance in Wholesale and retail trade, particularly for the 1930s, and its link to

[6] The assets selected to have embodied the great inventions are: communication equipment (ep20), medical equipment and instruments (ep33), nonmedical instruments (ep36), photocopy and related equipment (ep31), office and accounting equipment (ep12), electrical transmission, distribution and industrial apparatus (ei60), trucks, buses and truck trailers (et10), autos (et20), aircraft (et30), ships and boats (et40), railroad equipment (et50), electrical equipment, n.e.c. (eo70).

transportation improvements, was emphasized by Field (2011: 59, 65-7). Over the entire period, manufacturing accounts for only about a quarter of total value added. Confining a discussion of productivity performance to that sector alone is potentially quite misleading. Strong productivity growth for the whole economy would normally require other sectors to make significant contributions. Farming was still quite sizeable. This suggests that it is appropriate to analyse productivity in the market economy primarily through the performance of the PDE, as Kendrick did, rather than the private non-farm domestic economy (PNE). Besides its size, other reasons to use the PDE include large labour quality impacts of labour moving out of agriculture and technical change within agriculture.

Table D5 (Appendix D) reports estimates of labour quality growth by industry for each period, which are more detailed than Kendrick's and also show faster labour quality growth overall. As noted above, these estimates take account of labour quality improvements within occupations and sectors, which is important in an era of rapidly improving educational attainment. While in 1900 only 11% of those aged 14-17 were enrolled in high school, by 1938 this had risen to 68% (Goldin and Katz, 2008). The discussion in Appendix D illustrates that the rapid labour quality growth between 1899-1941 indeed originated primarily from educational attainment increases. For the PDE, education accounted for nearly 50% of average annual labour quality growth. Also, because of the sectoral reallocation of labour, which mainly concerned workers moving out of agriculture, labour quality grew considerably faster for the PDE than the estimates at the industry level suggest. Apart from education and sectoral shifts, workers' increased average age also raised labour quality over the long run, while the increasing proportion of women largely offset the age effect.

Table D5 presents a picture not only of rapid labour quality growth, on average, but also one of substantial variation between sectors and over time. The highest figure (Telephone in 1929-1941) was 1.14% per year, while the lowest (Leather products in 1899-1909) was -0.71%. [7] Overall, the correction factors for labour quality applied to crude TFP are quite variable, making relative sectoral contributions to TFP after these adjustments look quite a bit different. Contrary to some priors, the correlations between labour quality growth and refined TFP growth (Table 2) are quite low across our 38 sectors, at just 0.10 for the whole period, 1899-1941. Paper, Rubber products, and Textiles experienced the fastest labour quality growth during this era.

The TFP growth rates reported in Table 2 are generally lower than those in Kendrick (1961), mainly resulting from our upward adjustment to labour quality growth. Between 1899-1941 we estimate PDE TFP growth at 1.3% per year compared with Kendrick's 1.7%. Obviously, this still represents a strong performance relative either to the nineteenth century or rivals like the United Kingdom. The fastest TFP growth during these years was in 1929-1941 for the PDE, but not for manufacturing, where TFP growth was much faster in the 1920s. Strong performance in the 1930s was relatively broadly based. It involved much of the services sector, including our residual sector, consistent with Field's (2011) conclusions based on a much less granular, 7-sector, disaggregation.

During 1899-1941, the 3 sectors with the highest TFP growth were Entertainment, Electric utilities and Transport equipment, all part of the 'second industrial revolution'. Each of these made regular appearances in the top 5 throughout the period, but a further 9 sectors featured at least once in the top 5. More generally, rank correlation coefficients for sectoral TFP performance between successive periods were quite low (0.4, 0.0, and 0.2). There are 25 observations (about 16%) with negative TFP

[7] The many sectors with negative labour quality growth in 1899-1909 reflect the workforce becoming younger and including more women when educational attainment was rising less quickly than in later decades.

growth. Thirteen of these were for 1909-1919, years possibly affected by World War I. The 6 sectors whose TFP growth fell by at least 2.0 percentage points between 1899-1909 and 1909-1919, showed an average TFP growth improvement of 4.8 percentage points between 1909-1919 and 1919-1929.

Table 3 displays estimates of sectoral IGCs. The sum of negative IGCs was small – below 10% of total TFP growth in each decade, except for 1909-1919. The IGC depends both on TFP growth and a sector's size. The sector with the fastest TFP growth never had the largest IGC in any period. The top 3 IGC sectors during 1899-1941 were Wholesale and retail trade, Railroads, and Farming, none of which would be thought of as an exciting new, technologically progressive industry.[8] Wholesale and retail trade had a value-added weight of 14.1% and benefited from improvements in transport and communications and increased store sizes (Field, 2011), but would not usually be considered at the heart of the second industrial revolution. Over the whole period 1899-1941, it provided the largest IGC, but ranked only 24th in TFP growth. Likewise, Farming was a large, unglamorous sector (with a value-added weight of 10.5%) that had low TFP-growth but ranked third in IGC. Manufacturing's IGC dominated in 1919-1929, when it accounted for about three quarters of all TFP growth. This was exceptional and its average contribution over 1899-1941 was 'only' about forty percent. It was, however, still well above its value-added weight of about a quarter of GDP.

4. The Most Technologically Progressive Decade?

Field (2003) concluded that the 1930s, defined as 1929-41, were the most technologically progressive decade of the twentieth century, based on that period having the fastest TFP growth in the PNE. Field also noted that the 1930s saw unusually broadly-based TFP growth in terms of sectoral contributions. In this section, we re-examine the first of these claims using the new estimates that we reported in section 3, leaving our discussion of sectoral contributions to the next section. We will first discuss our baseline estimate of 1930s TFP growth, and then do sensitivity tests for three adjustments proposed by others: a cyclical adjustment, a revised capital depreciation rate, and the use of chain-linked price deflators. Finally, we test the robustness of our baseline estimate using the dual growth accounting method, which is based on prices rather than quantities.

In Table 4, we compare PDE TFP growth rates over the long twentieth century. The post-1948 estimates are taken from the Bureau of Labor Statistics (BLS, 2014). Based on our new estimates, the 1930s no longer report the fastest TFP residual. We agree with Field (2003) that TFP growth was undoubtedly strong and arguably quite remarkable for an economy experiencing the Great Depression. Yet our findings support the hypothesis that it was still somewhat below the TFP growth experienced during the Golden Age (1948-1973). Nevertheless, TFP growth at almost 1.9% per year makes the fears of secular stagnation expressed by Alvin Hansen (1939) seem misplaced.

There are a number of reasons why our findings differ from those of Field (2003). First, as remarked in section 3, we follow Kendrick (1961) in basing our comparisons on the PDE rather than the PNE, because in our view the then large and dynamic agricultural sector cannot be ignored as it was a fundamental part of the transformation taking place within the whole economy. Second, we suggest that Kendrick's pre-1948 figures (on which Field (2003) based its claims) are not readily comparable with the post-1948 estimates. The methodology we use makes our pre-war estimates more compatible with the more

[8] They were not identified by Mowery and Rosenberg (1989) as especially R&D intensive. The leaders in that respect were Chemicals, Petroleum, and Electrical machinery.

recent BLS growth accounts for the post-war era, particularly with regard to the labour quality adjustment and, post-1929, the estimation of capital services.

To see how the updated methodology affects the productivity estimates, Table 1 breaks down the growth in the PDE for the period 1929-41. It compares our own estimates with Kendrick's (1961) original estimates, used in Field (2003) to support its case. The difference between Kendrick's capital input contribution and our own is fully accounted for by the adjustment in the composition of capital (i.e. capital services). Our new labour quality estimate exceeds Kendrick's by accounting for educational attainment improvements within occupations, as noted in section 2. Given the increase in factor inputs, our TFP residual is considerably reduced compared with Kendrick's original figure (1.86% vs. 2.27% per year).

A later study, Field (2011: 43, 100, 169-91), made a cyclical adjustment to Field's (2003) original calculation. This raises the estimate of (underlying) TFP growth for the PNE from 2.31 to 2.78% per year, or, after chain-linking (Field 2013; see below), from 2.54 to 2.97% per year. The rationale for this 0.43-0.47 percentage-points adjustment was that 1941 is not an ideal (peacetime) peak year, even though it was the first year since 1929 that BLS unemployment averaged less than 10%. In 1941, unemployment was higher (9.9%) than in 1929 (3.2%) or 1948 (3.8%). Because of productivity's pro-cyclical nature, Field argues that TFP would have been higher in 1941 had the economy operated at full capacity, mainly because of capital hoarding effects. Based on a regression of changes in log TFP on changes in the unemployment rate, he argued that TFP would have been 5.6% higher if the economy had been at full employment in 1941. This would raise the average annual TFP growth rate by 0.47% for 1929-41 (Field 2011: 98-100).

We are not convinced that Field's cyclical adjustment is warranted. First, it is quite possible that the output gap had closed by 1941, or at least was much smaller than a comparison of headline unemployment figures with 1929 or 1948 would seem to suggest. Second, we note an analysis showing that a capacity utilization adjustment to TFP in manufacturing is inappropriate after 1937. We discuss these points in turn.

As macroeconomists know only too well, it is difficult to estimate the output gap, especially in an economy that has experienced severe shocks. To complicate matters further, it is debatable whether relief workers should be classified as unemployed, as they are in the series used by Field, or employed, as in Darby (1976) and Weir (1992). Weir's unemployment estimates for 1929, 1941 and 1948 are 2.89, 5.99 and 3.73 per cent, respectively, which makes the gap between 1941 and the comparison years a good deal smaller.

There are respectable arguments either way as to whether a cyclical adjustment is appropriate. On the one hand, the American economy generated more output with lower unemployment during the war years and the post-war unemployment rate remained below the 1941 level. On the other hand, estimates by Hatton and Thomas (2010) suggest a big rise in the NAIRU during the 1930s. Their estimate implies that by 1941, in peacetime conditions, the economy was already below the NAIRU.[9] Gordon and Krenn (2010) compared potential and actual output. They estimated an output gap of -3.1 per cent in the third quarter of 1941, but +0.3 per cent in the fourth quarter.

[9] Accelerating wage inflation offers some support for this. Nominal wages in all industries rose by 2.6 per cent in 1940, 10.6 per cent in 1941 and 17.9 per cent in 1942 (Carter, 2006: Ba4419).

Robert Inklaar et al. (2011) provided a test of the cyclical nature of productivity in the interwar U.S. economy. They found robust evidence of short-run increasing returns to scale, which they used to calculate a 'purified' measure of technological change. This confirms that "the hoarding of production factors was the dominant reason for the decline in measured Solow residual TFP in U.S. manufacturing between 1929 and 1933" (Inklaar et al. 2011: 851). In the period 1933 to 1937, however, TFP grew much faster than technology, because of a rapid expansion of factor inputs' utilization. In the years leading up the Second World War the discrepancy between TFP and technology had vanished. This suggests that capital hoarding was not prevalent in 1941.

In the light of this evidence, on balance, we prefer not to make a cyclical adjustment to TFP growth. If Field's adjustment is made, as noted earlier, this would add 0.43 percentage points per year to TFP growth. A revised adjustment using Field's regression coefficient with unemployment rates from Weir would add 0.17 percentage points per year to TFP growth (Table 5).

Field's (2011) proposal also implies true capital inputs are overestimated by conventional growth accounting methods, which do not adjust for capacity utilization. In contrast, Gordon (2016: 659-663) argues that capital inputs are seriously underestimated by standard growth accounting and hence TFP growth is exaggerated. In particular, he questions whether the depreciation rates, which are fixed over time, are representative for the Depression era. As investment collapsed, Gordon believes that all assets' expected life-time increased substantially. This lower depreciation rate would lead to a greater capital stock increase than suggested by the BEA estimates. To proxy these varying depreciation rates, Gordon suggests multiplying official depreciation rates by the ratio of investment to the official capital stock, for each year relative to the average for 1925-1972. When applied to our capital input estimates, this procedure reduces PDE TFP growth during 1929-41 by 0.18% per year (Appendix C). No evidence, however, is available to validate Gordon's assumptions about delayed capital retirement.

In a recent re-working of the Field (2003, 2011) estimates, Field (2013) drops the Kendrick output series in favour of more recent NIPA data, based on annual chain-linking of prices to deflate nominal output. Field uses this as the basis for a new calculation. The new output series grows faster than the old Kendrick series (based on 1929 prices), because the GDP deflator has changed, implying higher TFP growth. Field (2013) now finds that average PNE TFP growth during 1929-41 was 2.54% per year, or 2.97% after making a cyclical adjustment.

Although there are often good reasons to adopt annual chain-linking of the price index, it is known to be potentially misleading during periods of cyclical volatility because of the 'chain drift' problem. Generally, short frequency chaining is not an issue in an environment of steady change. In periods dominated by oscillations in relative prices, quantities, or both, indices can become highly susceptible to drift. In these cases, the index does not return to unity, even when prices in the current period revert to their original base-period levels. The 1930s and 1940s are characterized by large oscillations in the form of the Great Depression, the recession of 1937-8 and *in extremis* the Second World War.

To illustrate, we reweighted real GDP growth during 1929-69 for NIPA's detailed expenditure categories, based on peak-year relative prices. We then compare them to the reported annually chain-linked NIPA estimates.[10] For stable periods, such as 1948-60 and 1960-69, output growth based on an annually

[10] Using prices and nominal output for 115 expenditure categories from NIPA (2015) tables: 10104, 10105, 20404, 20405, 30904, 30905, 31004 and 31004. Peak years are 1929, 1941, 1948, 1960, 1969.

chained index lies about midway between growth with start-year and that with end-year weights. It thus closely approximates the geometric mean (i.e. Fisher index) of the fixed-base growth rates. This is not the case for the disturbed periods 1929-41 and 1941-48. In the former period, the end-year (1941) index estimates 2.55% growth per annum, the initial-year (1929) index 2.73%, and the Fisher index 2.63%. At 2.87%, growth of the annually chained index is well above the fixed weight indices and appears to be an outlier.[11] Generally, this disparity would be seen as an indication of chain drift (Ehemann 2007). In the presence of chain drift, the fixed-base Fisher index might be regarded as a reasonable alternative to the official chain-linked estimates.

Apart from the weighting procedure, the BEA has also updated prices and volumes in the US national accounts. This potentially necessitates an adjustment to Kendrick's original estimate for growth in the PDE. Lacking output-by-industry data prior to 1947, 1929-41 output growth in the PDE is difficult to distil from the NIPA tables. As a rough proxy, we deducted national and local government's value added from GDP and re-estimated real PDE growth based on the geometric mean of the start- and end-year weighted output indices. Using the recent NIPA figures, this exercise shows output growth to be only 0.12 percentage points above the 2.21% growth per annum listed by Kendrick (1961: 333-5). This is a modest difference, both in absolute terms and relative to the gap in TFP growth between 1929-41 and 1960-73 (Table 4). In the light of this and since the PDE estimates based on the NIPA figures are of an approximate nature, we prefer Kendrick's original estimates over the most recent output figures.

We accept that Field's (2011, 2013) and Gordon's (2016) procedures would materially affect the estimated TFP growth rate for the 1930s. We summarize the implications of their alternatives with a 'ready reckoner' (Table 5) of their approximate deviation from our baseline estimate. Comparing Tables 4 and 5, we see that the only single way to restore 1929-41 to being the period with the highest TFP growth, is to make a cyclical correction of the size proposed by Field.[12]

As a final robustness test of our findings for 1929-41 we also computed 'dual' TFP. This relies on indexes of prices for output and input, instead of quantities (Griliches and Jorgenson, 1967). The reasoning behind this 'dual' approach to productivity change is very similar to that of our previously reported 'primal' TFP. Any output price reduction not resulting from the (weighted) change in nominal wages or the rental price of capital, represents a shift in the production function.[13] Table E1 (Appendix E) shows that, for the PDE in 1929-41, dual TFP (1.82%) was very similar to our primal (1.86%) estimate. BLS (2014) dual TFP estimates confirm that 1960-73 showed significantly higher rates of TFP growth, at 2.25% per annum.

In sum, the TFP growth rate reported in Table 4 is our preferred estimate, even though we understand that others may wish to adopt one or more of the variations from our baseline, listed in Table 5. We do not think it is desirable to make a cyclical adjustment, or to deviate from conventional depreciation

[11] For 1929-41, growth of the annually chained index is always higher than the indices for any fixed-weight base year.

[12] Or alternatively using multiple adjustments from Table 9; i.e. this paper's revised cyclical adjustment on line 2, combined with Field's (2013) Chain-Linked Output revision on line 3.

[13] Appendix E provides a full description of the sources and methods.

rates for the capital stock, or to adopt chain-linked real output measures. We conclude that TFP growth for the PDE in the 1930s was most likely lower than in 1948-60 and 1960-73.[14]

5. Did the Great Inventions Dominate TFP Growth?

In the early twentieth century, most industries made a substantial contribution to overall TFP growth. At the 38-sector level, the IGC was distributed widely. No single industry dominated TFP growth in any given period (Table 3). This was true for manufacturing sectors as well as other industries, suggesting that not one but several factors sustained broad-based technological change across the American economy. At the more aggregated level, our findings are also consistent with Field's (2011) conclusion that the manufacturing sector as a whole was responsible for much of the TFP growth in the 1920s, but for far less in the 1930s.

In a well-known account of American economic growth, Gordon (2016) describes a 'special century' of TFP growth, reaching its apogee between 1920-1970, when the ramifications of the second industrial revolution held sway. This revolution was driven by 'great inventions' in four technology clusters: electricity; the internal combustion engine, together with derivative inventions such as interstate highways and supermarkets; rearranging molecules; and the entertainment, communication and information sector.[15] Gordon (2016) did not quantify these clusters' growth contribution over time. Thus, the question remains whether or not the great-invention sectors dominated overall TFP growth. In considering this issue, a standard of comparison is useful. For this we can turn to the first industrial revolution. Here it is widely accepted that TFP growth was concentrated in relatively few 'modernized' sectors, namely, cotton and woollen textiles, transport and iron. During 1780-1860, they accounted for 65% of TFP growth in the British economy, according to the estimates in Crafts (2018).[16] It would be fair to say that these modernized sectors dominated TFP growth during this period. This raises the question whether the great inventions of the second industrial revolution were similarly important.

Answering this question raises some problems. First, do we take account only of direct contributions to TFP growth, or should an estimate of (unremunerated) TFP spillovers also be included?[17] If we attempt the latter, the issue arises as to what methodology to use. We follow earlier writers in looking for correlations at the sectoral level between the growth of capital equipment embodying the great inventions and TFP growth. Second, is the taxonomy based on Gordon (2016) appropriate? Here the key issue is how to treat the Wholesale and retail trade sector, which made a large contribution to aggregate TFP growth, notably in the 'technologically progressive' 1930s. This sector would not

[14] For the PNE concept which Field (2003) prefers, the difference between the post-war period and the 1930s becomes very small: 1.93% per annum for the 1930s versus 1.99% per annum for 1960-1973, a difference of just 0.06 percentage points, or about 3%.

[15] We define the great inventions sectors as Oil and gas mining, Chemicals, Petroleum and coal products, Rubber products, Electric machinery, Electric utilities, Transport equipment, Wholesale and retail trade, Local transit Telephone, and Spectator entertainment (Table 6).

[16] Based on updating Harley's (1999) earlier well-known calculations to take account of Broadberry et al.'s (2015) GDP growth revisions (Table 9). For an alternative calculation arriving at approximately the same 2/3 contribution from the modernized sectors, see Clark (2014). Neither of these estimates includes inter-sectoral TFP spillovers.

[17] In principle, TFP spillover effects are distinct from the capital-deepening contribution to labour productivity growth from investment in new forms of capital goods embodying the great invention technology. They essentially represent externalities, for example, in the form of learning effects which enhance TFP, while capital deepening entails financial outlays which are expected to earn a rate of return. In general, the existence of TFP spillovers is quite controversial.

normally figure as a part of the second industrial revolution but clearly benefited from technologies invented in that revolution. Even so, it is not obvious that this sector's TFP growth derived entirely from the great inventions' spillover effects. Therefore, we calculate the great inventions' contribution both with and without Wholesale and retail trade.

Turning first to an analysis without such spillover effects, Table 6 confirms that the great inventions contributed a considerable share to TFP growth. In the 1900s, using the taxonomy based on Gordon (2016) and including Wholesale & retail trade, these sectors contributed 29% of TFP growth in the PDE, which subsequently rose to 45% in the 1930s. In absolute terms, the increasing contribution to annual TFP growth was even more pronounced, rising from 0.27 percentage points in 1899-1909 to 0.84 percentage points in 1929-41 (Table 3). The average over 1899-1941 was 0.49 percentage points - similar to the contribution of the entire manufacturing sector. Wholesale and retail trade, however, looms large in these numbers. Reclassifying this sector as outside the realm of great inventions, would reduce the great-invention share to 18% of TFP growth in the 1930s, and 21% of TFP growth over 1899-1941.

The great-invention sectors were very important. They accounted for about 38% of total TFP growth in 1899-1941. Yet, they did not contribute anything like as large a share of TFP growth as had the 'modernized sectors' in the first industrial revolution. The sources of TFP growth were more diverse than a reader of Gordon might suppose. The great inventions did not dominate as textiles, transport and iron had in Britain a hundred years before. The great inventions also accounted for a smaller proportion of TFP growth than did ICT in the so-called third industrial revolution. Over 1974-2012, ICT-producing sectors contributed about 54% of PNE TFP growth, 0.43% per year out of 0.79% (Byrne et al., 2013). The percentage point contribution of ICT to TFP growth was a little lower than that of the great inventions taken together (0.43 vs. 0.49 percentage points per annum). However, the weak TFP growth in the rest of the American economy gave ICT a relatively high share of overall intensive growth (54%, vs. 38% for the great inventions), and thus a stronger claim to have been a 'dominant technology'.

We now extend our estimate of the great inventions' TFP growth contribution to include TFP spillovers. These are estimated following David (1991), who looked at electricity spillovers in the 1920s. Devine (1983) identified electricity as a source of spillovers. He noted several reasons why spillovers might flow from changes in factory design. Facilitated by the shift to machinery with unit drive, electricity enhanced flexibility of production, improved materials handling, made single-storey plants feasible, and allowed for lighter factory buildings, all capital-saving. Horsepower in secondary motors in interwar manufacturing grew rapidly, averaging 14% per year between 1919-1929 and 2.9% between 1929-1939 (DuBoff, 1979).

To estimate electrical spillovers' size, we run cross-section regressions similar to David (1991), linking the accelerations in TFP growth to the growth of secondary electric motors per unit of labour (Table 7). We use our own TFP growth estimates and a larger sample of manufacturing industries compared to David.[18] In regression (1), we find evidence in favour of TFP spillovers for the 1920s, but in regression (2) we cannot reject the null hypothesis for the 1930s. This is perhaps not surprising, since the literature has singled out the 1920s as the period when electricity had the highest impact. We agree with David (1991) that spillovers were important but our results show that electricity spillovers accounted for about a quarter of manufacturing TFP growth, compared with nearly one half according to David (1991).

[18] This is quite similar to Stiroh's (2002) approach to investigating TFP spillovers from ICT capital accumulation in the late twentieth century.

We run a similar exercise for the 1930s, where we now estimate the size of the TFP spillovers based on flows from the increase in the services of great inventions capital, instead of just electricity. For manufacturing, regressions (3) and (4) in Table 7 show a significant and positive relation between the growth in great inventions' capital services and the acceleration of TFP growth. Extending the sample to include all industries in the PDE nullifies this result. We therefore use the results from regression (3) to estimate spillovers only within manufacturing.

Table 8 presents the contributions to labour productivity growth in interwar manufacturing and the PDE. This takes account of TFP spillovers using regressions (1) for 1919-29 and (3) for 1929-41 to estimate the impact of the growth of electric motors and great-inventions capital services. If these spillovers are added to the share of the great inventions' TFP contribution in the PDE, this rises by about 10 percentage points in both periods: to 50% of the aggregate in the 1920s (0.81/1.63), and to 56% in the 1930s (1.05/1.86). Finally, even including spillover effects, electricity did not dominate TFP growth in the 1920s, when it was supposed to have exercised a pervasive effect. We estimate that the direct effects (0.029 + 0.042), plus spillovers in manufacturing (0.16), add up to a TFP growth contribution for electricals of 0.23 percentage points per year, about 14% of the 1.63% annual PDE TFP growth (Tables 4 and 8).

Our estimates of TFP spillovers should be regarded as a pioneering attempt to fill an important gap in the evidence base. Although we agree with Gordon (2016) that the 'great inventions' were important, their overall contribution to TFP growth was lower than what one might expect after reading Gordon (2016). They did not contribute as large a share of TFP growth as had the 'modernized sectors' in the first industrial revolution.[19]

6. Three Implications

When we link our detailed 38-sector TFP growth disaggregation to findings from the literature we note three implications: how the first and second industrial revolutions compare, the importance of services in outperforming interwar Britain, and whether TFP growth is a good measure of R&D productivity. A key feature of our estimates is that TFP growth was broadly based and almost pervasive. Many sectors had a significant impact on aggregate TFP growth. For the whole period 1899-1941, all but five sectors averaged at least 1% per year (Table 2).

First, we highlight a major difference between the first and second industrial revolutions, hitherto unremarked. It is certainly true that great-inventions sectors' TFP growth of the early 20th century exceeded that in the modernized sectors of the early 19th century. Yet the stronger TFP growth in the second industrial revolution owed much more to faster TFP growth in the rest of the economy. The US great inventions sectors' average TFP growth was 2.1% per year during 1899-1941, compared with 1.2% in the British modernized sectors during 1780-1860 (Table 9). The US leading sector, Electric utilities, saw TFP growth of 5.0% per year, compared with 1.9% in its British predecessor, Cotton textiles. Nevertheless, more important for overall TFP growth in the second industrial revolution was the improvement in TFP growth in the rest of the economy (1.0% per year), compared with the earlier British experience (0.25%). If the 20th century great-inventions sectors' TFP growth was reduced to that

[19] Excluding TFP spillovers, for which estimates lack for the First Industrial Revolution, but including Wholesale and retail trade, the great inventions' share of TFP growth was just over half that of the 'modernized sectors' in the earlier period.

of the 19th century modernized sectors (1.2% per year), their contribution to total TFP growth would have fallen by 0.22 percentage points per year (Table 9, Counterfactual I). However, if the remainder of the economy's TFP growth was reduced to 0.25%, its contribution would have fallen by 0.60 percentage points per year (Table 9, Counterfactual II).

Second, market services TFP growth was a key component of the US productivity performance during the second industrial revolution. Between 1899-1941, the service sectors listed in Table 3 accounted for 34% of TFP growth, only a few percentage points less than manufacturing. This underscores that the large share of manufacturing in aggregate TFP growth in the 1920s was exceptional. Field (2011) made this point well in comparing the 1920s and 1930s, but we place his claim on a firmer footing and show that it holds good when taking into account the earlier decades.

The strong showing of American services TFP growth also marks a salient contrast with Britain. It supports Broadberry's (2006) emphasis that America overtaking Britain as the leading economy owed a lot to its superior progress in services. It is now possible to provide additional quantification to support this argument.[20] A comparison of crude TFP shows that all US sectors, except Mining and Construction, contributed more percentage-points to TFP-growth than the British sectors (Table 10). The bigger difference was in services. Whereas US manufacturing contributed 0.4 percentage points per year more to TFP growth than British manufacturing, US Market services contributed 0.6 percentage points more (Table 10). While the value-added shares were broadly similar, the shares in aggregate TFP-growth (the IGCs) differed sharply. Services held 35-36% of value added in both countries, but in the US accounted for 27% of aggregate TFP-growth and in Britain for minus 3%. Conversely, Agriculture, Mining, Manufacturing, Utilities and Construction all had considerably larger IGCs in Britain. Because 'Commerce' (FIRE and Distribution) comprised a quarter of the economy in both countries, the difference between minus 0.5% TFP growth in Britain and plus 1.1% in America had a disproportionate impact on aggregate growth.

Third, the pattern of IGCs we have identified can illuminate the role of R&D in underpinning TFP growth. We link the IGCs to National Research Council survey data on R&D in manufacturing reported by Mowery and Rosenberg (1989). Popular narratives emphasize the greatly enhanced role of laboratory-based science and technology in the much-improved productivity performance of the early 20th century. Bloom et al. (2017) link TFP growth to R&D inputs from the 1930s to the 2010s, suggesting that 'ideas are getting harder to find'. Our detailed sectoral TFP growth estimates put us in a unique position to investigate some aspects of this approach empirically for the interwar period.

R&D indicators for manufacturing industries and TFP growth show a weak relationship, with limited correlation in some instances but none in others. Regressing the log growth acceleration of TFP for the 1920s on the log of research intensity in 1921suggests that raising research intensity by 1% near the mean of one scientist per 2,000 wage earners would increase TFP growth acceleration by a little under 0.2 percentage points (Figure 1). Yet the same exercise for the 1930s yields a negative coefficient and using other R&D indicators yields even less robust relationships (Appendix F). Five industries with no R&D Labs whatsoever before 1919 accounted for 18% of 1920s TFP growth, while industries with half the R&D labs founded before 1919 accounted for just 16%. Chemicals alone harboured almost 30% of labs founded before 1919, 40% of all research scientists employed in 1921, and 20% of additional scientists hired until 1927, but accounted for only 7% of TFP growth in the 1920s and 5% in the 1930s.

[20] The sectoral comparison in Table 10 can only be conducted on a crude TFP basis, i.e. not taking into account labour quality changes, and only by comparing 1919-1941 for the US with 1924-1937 for Britain for selected sectors, using Matthews et al.'s (1982) research.

While Chemicals had the second-highest TFP growth acceleration in the 1920s, it had the third-lowest in the 1930s. Clearly, if there was a one-to-one relationship between R&D and TFP one would expect Chemicals to have a much higher IGC.

Sources of TFP-growth were diverse, each likely to diverge considerably in importance across industries. Outside manufacturing, the big Wholesale and Retail Trade sector hardly did any R&D but accounted for 15.4% of interwar TFP growth—almost as much as the combined manufacturing industries that accounted for half the R&D labs founded before 1919. It is evident that the relationship between R&D and productivity was not zero, and R&D productivity may well have declined, as Bloom et al. argue. Yet, our analysis of the interwar data suggests that Bloom et al.'s temporal comparison from the 1930s to the 2010s could potentially exaggerate the extent of the decline. Our cross-sectional study of 1920s and 1930s manufacturing finds that the link between R&D and TFP was much weaker than many economists might have imagined, or than many an endogenous growth theory might model.

While R&D certainly was important, it was not a dominant factor in interwar TFP growth. Clearly, TFP growth does not equate one-to-one to technological progress. It is 'the measure of our ignorance' and includes other aspects of economic change such as improvements in allocative and productive efficiency. The American economy during the second industrial revolution held significant scope for such advances and this deserves more research. Nevertheless, the literature already points to this conclusion. Following Hsieh and Klenow's (2009) methodology, Ziebarth (2013) estimates that production factor misallocation in the late 19th century US, was on par with China and India in the late 20th century. Examples of 1930s' TFP growth stemming from exit of the inefficient have been highlighted. These include the closure of low-productivity car plants (Bresnahan and Raff, 1991) and grocery stores (Baskers, Vickers and Ziebarth, 2018). Last, a significant fraction of TFP growth reflected improvements in management techniques (Alexopoulos and Tombe, 2012).

7. Conclusions

This paper provides a significantly improved account of U.S. TFP growth between 1899-1941. We have advanced and extended Kendrick's (1961) seminal work in five ways. First, we cover more sectors in detail. Second, we take better account of labour quality. Third, we estimate the capital input contribution on a capital-services basis where feasible. Fourth, we extend the analysis from 1937 to a more suitable endpoint at 1941. Fifth, using value-added weights, we calculate intensive growth contributions in a 38-industry disaggregation. The resulting improved growth accounting estimates lead to four significant advances. We discuss these in turn.

First, our estimates find that TFP growth in the PDE averaged 1.3% per year during 1899-1941. This compares with Kendrick's estimate of 1.7%. The difference results mainly from the labour quality adjustment to crude TFP. We estimate that labour quality grew at 0.8% per year, which is considerably higher than Kendrick's 0.3%. This is primarily because we took explicit account of educational attainment improvements within occupations. These were quite significant as years of schooling were rising steadily. Our estimates undermine Solow's famous (1957) claim that the residual was responsible for about 7/8th of labour productivity growth. We believe that TFP growth accounted for 'only' about 60%.

Second, our estimates allow us to calculate TFP growth during the Great Depression on a more fully comparable basis with the post-war years. Our method of correcting TFP for labour quality improvements is similar to the BLS approach for the post-war era. This allows us to make inter-temporal comparisons more accurately than hitherto. This is especially so for 1929-41, where we could also estimate capital-services based capital inputs. This leads us to the finding that the 1930s probably was not the 'most technologically progressive decade of the twentieth century' (Field, 2003), since our PDE TFP growth estimate is below that achieved in both 1948-60 and 1960-73. Our alternative TFP growth estimate, using the dual approach, confirms this. It even shows a slightly bigger performance gap between the 1930s and 1960s. Nevertheless, it is still true that 1929-1941 showed a strong productivity performance. Our estimate is that PDE TFP growth averaged about 1.9% per annum, the highest pre-war growth rate. This makes Hansen's (1939) fears of secular stagnation seem implausible.

Third, our estimates allow us to disaggregate TFP growth into sectoral contributions more fully than before. We provide a detailed 38-sector account of industry contributions to aggregate TFP growth, showing that the latter was broadly based during most of 1899-1941. It appears that TFP growth accrued across the economy from multiple disparate sources. The sectors which a reader of Gordon (2016) could identify as comprising the 'great inventions', made a substantial direct contribution, averaging just under 40% of TFP growth. Yet they did not represent a dominant component to the extent that the key technologies of the first industrial revolution did. This conclusion survives when we take account of TFP spillovers across sectors.

Fourth and finally, our disaggregated estimates shed light on the role of R&D inputs in TFP growth during the interwar years. TFP growth before World War II was broadly based, with important contributions from many sectors. It reflected more than just technological progress. At the sectoral level we find that it was not closely correlated with R&D inputs. We certainly do not argue that R&D and TFP growth are completely unrelated, and R&D productivity may well have declined since the 1930s, as Bloom et al. (2017) suggest. Yet we are not convinced that the high ratio of TFP growth to R&D is a good measure of the productivity of researchers in the interwar period, nor that it necessarily implies that ideas were much easier to find at that time.

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Table 1. *Sources of Growth in the Private Domestic Economy (PDE): BCW and Kendrick, 1899-1941 (percent per annum).*

		1899-1929		1929-41		1899-1941	
		BCW	Ken-drick	BCW	Ken-drick	BCW	Ken-drick
1	Labour productivity ((2)+(5)+(6))	2.04	2.04	2.48	2.48	2.16	2.16
	Contributions from:						
2	Capital input ((3)+(4))	0.38	0.38	0.15	0.04	0.31	0.28
3	Capital stocks	0.38	0.38	0.04	0.04	0.28	0.28
4	Capital composition			0.11		0.03	
5	Labour composition	0.59	0.25	0.46	0.16	0.55	0.22
6	Total factor productivity	1.07	1.42	1.86	2.27	1.29	1.66

Notes: BCW refers to this paper. All variables are expressed in per hour terms. We applied a capital share of 32% for the period 1899-1929 and 23% for 1929-41, based on Kendrick (1961: 285). Growth rates in natural logarithms. Contributions may not sum to total due to rounding.

Sources: own calculations and Kendrick (1961: 333-5).

Table 2. *Growth in Total Factor Productivity (TFP) by Industry, United States, 1899-1941.*

Industry	TFP-growth (percent per annum)				
	1899-1909	1909-1919	1919-1929	1929-1941	1899-1941
Farming	-0.2	-0.7	1.1	2.5	0.7
Metals	1.0	1.8	3.4	0.6	1.6
Anthracite Coal	-0.5	0.1	-0.4	0.3	-0.1
Bituminous Coal	1.0	1.5	2.0	1.8	1.6
Oil and Gas	1.3	1.0	4.8	2.1	2.3
Non-metals	1.5	0.0	5.6	3.6	2.7
Foods*	0.5	-1.8	4.4	3.7	1.8
Tobacco	1.5	4.7	4.1	5.8	4.1
Textiles	0.7	0.4	2.4	3.3	1.8
Apparel	0.5	2.2	3.6	-0.4	1.4
Leather Products	0.6	0.3	2.7	-0.1	0.8
Lumber Products	-0.3	-1.5	2.1	-1.7	-0.4
Paper	1.7	-0.2	4.0	1.1	1.6
Printing Publishing	3.7	2.7	3.4	0.3	2.4
Chemicals	0.7	-1.1	6.8	2.1	2.1
Petroleum, Coal Products	0.5	-1.5	7.8	-1.1	1.3
Rubber Products	1.9	6.5	7.0	1.5	4.1
Stone, clay, glass	2.2	0.4	5.1	1.7	2.3
Primary Metals	2.6	-0.9	4.9	2.3	2.2
Fabricated Metals	2.3	1.4	4.1	1.3	2.2
Machinery Non-Electric	1.0	0.4	2.2	2.2	1.5
Electric Machinery	0.0	-0.1	3.1	4.7	2.0
Transport Equipment	1.2	6.7	7.6	3.6	4.7
Furniture	-0.5	-0.8	4.0	1.4	1.0
Miscellaneous	0.8	-1.0	3.9	1.6	1.3
Electric Utilities	5.0	7.6	2.3	5.2	5.0
Manufactured Gas	4.1	4.8	2.8	2.0	3.4
Natural Gas	0.1	1.0	-0.1	3.8	1.3
Construction*	4.3	-1.5	0.8	0.3	1.0
Wholesale & retail trade*	1.6	0.0	0.9	3.4	1.6
Railroads	1.8	2.9	1.3	2.6	2.2
Local Transit	1.0	2.2	3.6	0.4	1.7
Residual Transport	-1.3	1.4	6.7	5.6	3.2
Telephone	4.5	1.9	1.1	1.4	2.2
Telegraph	1.6	-1.3	4.4	0.9	1.3
Post Office*	1.4	2.5	0.1	0.8	1.2
FIRE*	0.7	-0.0	0.3	-1.4	-0.2
Spectator Entertainment*	4.0	10.8	3.2	4.4	5.5
Manufacturing	0.7	0.0	4.7	2.3	2.0
Great inventions*	1.4	1.0	2.7	3.2	2.1
Aggregate measured sectors	0.5	0.0	1.9	1.7	1.1
Residual sector	2.4	3.0	0.5	2.3	2.0
PDE	0.9	0.6	1.6	1.9	1.3
Memorandum:					
Kendrick's aggregate measured sectors	0.7	0.8	3.7	(2.5)	(1.9)
Kendrick's residual sector	1.7	1.5	-0.1	(2.0)	(1.4)
Kendrick PDE	1.2	1.1	2.0	2.3	1.7
Minimum	-1.3	-1.8	-0.4	-1.7	-0.4
Maximum	5.0	10.8	7.9	5.8	5.5
Range	6.4	12.6	8.3	7.5	6.0

Notes: * = sector measured in this paper but not by Kendrick. Kendrick's aggregate measured sector comprises Farming, Mining, Manufacturing, Transportation, Communication & Public Utilities). Growth rates calculated using natural logarithms.
Source: Kendrick 1961, 136-7; own calculations; see text; Appendices B, C, and D.

Table 3. Intensive Growth Contribution by Industry, United States, 1899-1941.

Industry	Intensive Growth Contribution (VA-share x TFP growth)				
	1899-1909	1909-1919	1919-1929	1929-1941	1899-1941
Farming	-0.031	-0.079	0.103	0.206	0.079
Metals	0.006	0.011	0.020	0.003	0.010
Anthracite Coal	-0.002	0.000	-0.001	0.001	0.000
Bituminous Coal	0.007	0.010	0.014	0.013	0.011
Oil and Gas	0.005	0.005	0.033	0.018	0.014
Non-metals	0.006	0.000	0.015	0.008	0.008
Foods*	0.022	-0.066	0.145	0.131	0.066
Tobacco	0.014	0.042	0.037	0.067	0.040
Textiles	0.014	0.008	0.046	0.062	0.034
Apparel	0.009	0.033	0.049	-0.006	0.020
Leather Products	0.005	0.002	0.017	0.000	0.006
Lumber Products	-0.008	-0.027	0.027	-0.014	-0.006
Paper	0.008	-0.001	0.024	0.008	0.010
Printing Publishing	0.054	0.043	0.060	0.005	0.039
Chemicals	0.007	-0.012	0.080	0.030	0.025
Petroleum, Coal Products	0.003	-0.014	0.103	-0.014	0.014
Rubber Products	0.004	0.020	0.028	0.007	0.014
Stone, clay, glass	0.016	0.004	0.045	0.016	0.020
Primary Metals	0.069	-0.024	0.122	0.054	0.056
Fabricated Metals	0.023	0.018	0.065	0.021	0.031
Machinery Non-Electric	0.024	0.010	0.048	0.044	0.032
Electric Machinery	0.000	-0.001	0.029	0.050	0.016
Transport Equipment	0.013	0.097	0.141	0.078	0.078
Furniture	-0.003	-0.005	0.027	0.010	0.006
Miscellaneous	0.007	-0.008	0.027	0.010	0.010
Electric Utilities	0.025	0.088	0.042	0.112	0.073
Manufactured Gas	0.005	0.007	0.005	0.004	0.006
Natural Gas	0.000	0.002	0.000	0.013	0.003
Construction*	0.239	-0.074	0.036	0.012	0.044
Wholesale & retail trade*	0.217	0.004	0.127	0.494	0.221
Railroads	0.116	0.177	0.076	0.119	0.123
Local Transit	0.012	0.024	0.037	0.003	0.018
Residual Transport	-0.015	0.018	0.094	0. 099	0.045
Telephone	0.014	0.010	0.008	0.012	0.014
Telegraph	0.002	-0.002	0.007	0.001	0.002
Post Office*	0.006	0.013	0.001	0.005	0.006
FIRE*	0.031	0.000	0.031	-0.158	-0.016
Spectator Entertainment*	0.016	0.050	0.017	0.025	0.027
Great inventions*	0.268	0.229	0.649	0.836	0. 494
Aggregate measured sectors	0. 345	-0.206	1.535	1.375	0.856
Residual sector	0.585	0.668	0.096	0.485	0.438
PDE	0.930	0.642	1.631	1.861	1.294
Mean	0.025	0.010	0.047	0.041	0.031
Coefficient of variation	2.157	4.316	0.852	2.283	1.322

Notes: * = sector measured in this paper but not by Kendrick.
Source: derived from Tables A1 and 2.

Table 4. *TFP Growth in the Private Domestic Economy, United States, 1899-2007 (percent per annum).*

Period	TFP-growth (percent per annum)
1899-1909	0.93
1909-1919	0.64
1919-1929	1.63
1929-1941	1.86
1948-1960	1.98
1960-1973	2.21
1973-1989	0.48
1989-2000	0.97
2000-2007	1.44

Note: the post-war break points are chosen on the basis of NBER business cycle peaks. Growth rates have been calculated using natural logarithms.

Sources: Table 3 and Bureau of Labor Statistics, 'Historical Multifactor Productivity Measures', http://www.bls.gov/mfp/home.htm (October 2014); National Bureau of Economic Research, 'US Business Cycle Expansions and Contractions,' http://www.nber.org/cycles.html (accessed 28 November 2015).

Table 5. *Deviations from Baseline TFP Growth Estimate for the Private Economy, 1929-1941, percentage-point per year.*

Treatment	Authors	Change (%-point p.a.)
Cyclical Adjustment	Field (2013)	0.43
Revised Cyclical Adjustment	BCW (2018)	0.17
Chain-Linked Output Adjustment	Field (2013)	0.23
Revised Output Adjustment	BCW (2018)	0.12
Revised Depreciation Rates	Gordon (2016)	-0.18

Note: BCW (2018) refers to this paper. All rates based on the PNE except for the last two – revised output and depreciation adjustment –, which are for the PDE. The revised output adjustment reflects the difference between growth of real output according to our preferred estimate by Kendrick (1961: 333-5) at 2.21% per annum versus the geometric mean of 1929- and 1941-weighted output growth (2.33% per annum) estimated by the current paper as a robustness check from NIPA (2015) expenditure data.
Sources: Field (2013); own calculations (see text and Appendix tables C3 and C4); Gordon (2016).

Table 6. *Intensive Growth Contribution by Industry, as share of TFP growth in the PDE, 1899-1941, percent of total.*

	1899 1909	1909 1919	1919 1929	1929 1941	1899 1941
All other sectors	71	64	60	55	62
Great-inventions sectors	29	36	40	45	38
Of which:					
Rearranging molecules	2	0	15	2	5
Electricity	2	11	4	9	7
Internal combustion engine	22	16	19	32	24
Entertainment, comm. and information	3	8	2	2	3
Memorandum Item:					
Wholesale and retail trade	23	1	8	27	17

Note: 'All other sectors' refer to TFP growth in the PDE, minus the IGC for the great inventions sectors. The great inventions sectors are for rearranging molecules: oil and gas mining, chemicals, petroleum and coal products, rubber products; for electricity: electric machinery, electric utilities; for the internal combustion engine: transport equipment, wholesale and retail trade, local transit; for entertainment, communication and information: telephone, spectator entertainment. To calculate the proportions of the four groups within the Great Inventions, it has been assumed that the effect on labour quality of workers shifting sectors was proportionate for each of the four constituent groups. Percentages may not sum to totals due to rounding.

Table 7. *Regressions of TFP Spillovers from 'Great Inventions' for a Cross-Section of Industries in the United States, 1919-1941.*

	Regression (1)	Regression (2)	Regression (3)	Regression (4)
Period	1919 - 1929	1929 - 1941	1929 - 1941	1929 - 1941
Independent variable	Electric Horsepower per Hour	Electric Horsepower per Hour	Great Inventions Capital per Hour	Great Inventions Capital per Hour
Sector	Manu-facturing	Manu-facturing	Manu-facturing	PDE
Intercept	2.41***	-2. 60**	-3.27***	-1.36***
	(4.04)	(-2.42)	(-4.94)	(-2.76)
Coefficient	0.19**	-0.01	0.21*	-0.03
	(2.19)	(-0.04)	(1.85)	(-0.33)
R^2	0.22	0.00	0.17	0.00
Adjusted R^2	0.17	-0.06	0.12	-0.03
Observations	19	19	19	37

Notes: t-statistics in parentheses; *** p < 0.01, ** p < 0.05, * p < 0.10. 'Great Inventions Capital per Hour' refers to the services rendered by Electrical Equipment, Electrical Instruments and Transportation Equipment. The dependent variable for regression (1) is the acceleration in TFP growth from the period 1899-1919 to the period 1919-1929. The dependent variable for regressions (2), (3) and (4) is the acceleration in TFP-growth from the period 1919-1929 to the period 1929-1941. These are derived from Table2. The independent variables are based on the average rates of growth of the variable per hour worked for 1919-1929 for regression (1), 1929-1939 for regression (2) and 1929-1941 for regressions (3) and (4). Repeating regression (2) with as dependent variable the acceleration in TFP growth from 1919-1929 to 1929-1939 yields very similar and similarly insignificant results ($R^2 = 0.00$; results available from the authors). No capital services data was available for Spectator Entertainment.

Table 8. *Contributions to Growth of Labour Productivity, 1919-1941 (percentage-points per annum).*

		1919-1929		1929-1941	
		Manufacturing	PDE	Manufacturing	PDE
1	Labour productivity ((2) + (3) + (4))	5.45	2.36	2.61	2.48
	Contributions from:				
2	Labour composition	0.43	0.46	0.33	0.46
3	Capital input	0.29	0.27	-0.04	0.15
4	Total factor productivity ((5) + (6) + (7))	4.73	1.63	2.32	1.86
5	Great inventions TFP	1.46	0.65	0.58	0.84
6	Electricity & great inventions spillovers	0.60	0.16	0.79	0.21
7	Other TFP	2.66	0.81	0.95	0.81
	Contribution great inventions TFP to labour productivity ((5) + (6))	2.06	0.81	1.37	1.05
	Share contribution to LP (((5)+(6))/(1)) (%)	38	34	52	42
	Share contribution to TFP (((5)+(6))/(4)) (%)	44	50	59	56
	Memorandum Item:				
	Wholesale and retail trade TFP		0.13		0.49

Notes: All variables are expressed in per hour terms. For the PDE we applied a capital share of 29% for the period 1919-29 and 23% for 1929-41 (Kendrick 1961: 285) For manufacturing the capital share was 23% in both periods (Kendrick 1961: 453). For the contribution to TFP growth, we take the great Inventions sectors to be identical to those listed in the notes to Table 6. Growth rates calculated using natural logarithms. Contributions may not sum to total due to rounding.

Sources: Labour productivity and capital input from Kendrick (1961) and Appendix C, Labour composition from Table D5, Great Inventions TFP from Table 3 of this paper, Great Inventions spillovers based on Table 6 of this paper.

Table 9. *The Industrial Revolution in Britain and the Second Industrial Revolution in the US, 1780-1941.*

	United Kingdom, 1780-1860				United States, 1899-1941			
	TFP	Share of			TFP	Share of		
	growth	VA	IGC		growth	VA	IGC	
	(% p.a.)	(%)	(%)	(%-point)	(% p.a.)	(%)	(%)	(%-point)
Actual								
Modernised sectors	1.2	29	65	0.33	2.1	23	38	0.49
Remainder	0.3	71	35	0.18	1.0	77	62	0.80
Total	0.5	100	100	0.51	1.3	100	100	1.29
Counterfactual I								
Modernised sectors	1.2				1.2	23	38	0.27
Remainder					1.0	77	62	0.80
Total					1.1	100	100	1.07
Counterfactual II								
Modernised sectors					2.1	23	38	0.49
Remainder	0.3				0.3	77	62	0.19
Total					0.7	100	100	0.69

Notes: the most progressive sector was Cotton Textiles (1.9% TFP growth p.a., accounting for 26% of aggregate TFP growth) in the UK and Electric Utilities (5.0% p.a. and accounting for 5% of aggregate TFP growth) in the US.
Sources: this paper; Crafts (1985); Deane and Cole (1962). UK value added weights for 1820 based on Deane and Cole (1962 p. 166) with industry allocated according to Crafts (1985, p.22)

Table 10. *American and British Crude TFP Growth for Selected Sectors, 1919-1941 and 1924-1937.*

	United States, 1919-1941				United Kingdom, 1924-1937			
	TFP	Share of			TFP	Share of		
	growth	VA	IGC		growth	VA	IGC	
	(% p.a.)	(%)	(%)	(%-point)	(% p.a.)	(%)	(%)	(%-point)
Agriculture	2.1	9	8	0.2	2.1	4	14	0.1
Mining	2.7	3	3	0.1	1.2	5	11	0.1
Manufacturing	3.8	26	45	1.0	1.9	31	83	0.6
Utilities	3.9	2	4	0.1	1.8	2	6	0.0
Construction	0.7	4	1	0.0	1.3	5	7	0.1
Market Services	1.7	36	27	0.6	-0.1	35	-3	0.0
Residual sector	1.2	20	11	0.2	-0.7	18	-19	-0.1
Total	2.2	100	100	2.2	0.7	100	100	0.7
Market Services								
Transport & Comms.	3.1	10	14	0.3	1.0	10	14	0.1
FIRE & Distribution	1.1	26	13	0.3	-0.5	25	-17	-0.1

Notes: UK services share corrected for financial services effect (MFO p 223). Aggregate refers to the PDE in the US and GDP in the UK. Distribution refers to Wholesale and Retail Trade.

Sources: this paper and Mathews, Feinstein and Odling-Smee (1982).

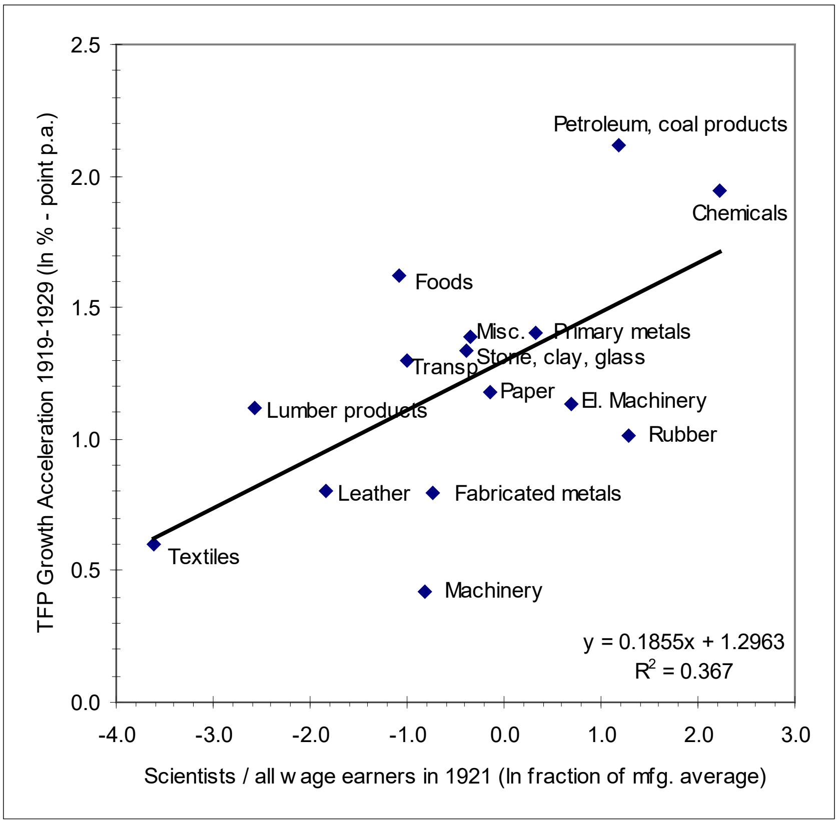

Figure 1. *TFP growth acceleration versus scientists per wage earner, for US manufacturing sectors, 1919-1929, logarithmic scale.*

Note: the scales on both axes are in natural logarithms of the values. The TFP growth acceleration refers to TFP growth for 1919-1929 minus TFP growth for 1899-1919. The average number of scientists per 1,000 wage earners in manufacturing was 0.56. Four industries (Tobacco, Apparel, Printing and Publishing, and Furniture) had no research scientists in 1921 and therefore were excluded from the above figure. Coefficient significant at the 5% level (p = 0.017), constant at the 0.1% level (p = 0.000), adjusted R^2 was 0.32.

Source: National Research Council surveys on R&D in Manufacturing, as reported by Mowery and Rosenberg (1989); Table 2 of this paper.

Online Appendices:

Appendix A: Sources for Value Added Weights

Three benchmark years have been chosen to calculate value added weights: 1899, 1929, and 1939. From these benchmarks, mid-period weights have been calculated using linear interpolation. Below we discuss the sources for each set of benchmark estimates in detail.

A1. Value Added Weights for 1899

Estimates of value added for electric utilities, farming, metals, mining, non-metals, oil & gas, and manufacturing industries other than those specified below have been taken from Whitney (1968). Value added in foods is the aggregate of 'processed foods' and 'grain mill products' in Whitney (1968). Within manufacturing, for tobacco, non-electric machinery, electric machinery, transport equipment, furniture, and 'miscellaneous' estimates have been taken from the *Census of Manufactures*. Estimates of value added in wholesale & retail trade and in FIRE have been taken from Carter et al. (2006, series Dh1 and Dh2), and estimates of value added in local transit and in railroads from Gallman and Weiss (1969, p.310).

Other sectors all entailed some computation which was implemented as follows:

Anthracite coal and bituminous coal has been estimated using Whitney's (1968) value added for coal mining and the U.S. Bureau of the Census (1960), series M 13-37, p. 350 to apportion the shares of anthracite and bituminous coal mining.

Manufactured gas and natural gas have been estimated using the gross output data in Gould (1946, Table A17), and then using the ratios of value added to gross output for 1919 from Kuznets (1941, p. 659, 661) to arrive at a value-added estimate for 1899.

Construction has been arrived at by calculating gross output from Abramovitz (1964) and then using the average gross output/value added ratio for 1919-1924 from Kuznets (1941, pp. 641-2) to estimate value added.

Residual transport comprised water transportation, pipelines and transportation services. Water transport value added has been taken from Gallman and Weiss (1969, p. 316). For pipelines a rough bench mark estimate has been made for 1885 based on Chandler (1990, p. 74, 94), who stated that Standard Oil's pipeline network was about 4,000 miles. It is assumed that total installed length was double this, i.e., 8,000 miles. This benchmark is then linked to the time series reported in Carter et al. (2006, series Df1246) for 1921-1939 using geometric interpolation, and an estimate for 1899 is made. Real gross output in 1929 from Kendrick (1961, p. 463) relative to pipeline length is then used to estimate real gross output for 1899. The ratio between the 1929 value added of 'Pipelines except natural gas' reported in the *National Income and Product Accounts*, and 1929 gross output for pipelines in Kendrick (1961) is then used to estimate value added for 1899. Value added for transport services has been estimated using the ratio of this to all other transport sectors in 1929 and applying this ratio to the value added of all other transport sectors in 1899.

Telephone is based on the value added of the Bell system companies for 1899, as reported in U.S. Bureau of the Census (1961, p. 481, series R 14-27), multiplied by the inverse of its estimated share in all telephone value added. The latter has been estimated by taking the shares (weighted by local-exchange and long-distance calls) of the Bell companies and the independent companies in 1900, and back-projecting this ratio to 1899 taking into account the differential growth rates of the number of telephones for the two systems.

Telegraph value added comprises the 'International telegraph industry' and the 'Domestic telegraph industry'. The former has been estimated taking operating revenues from Carter et al. (2006, series Dg18), and using the 1907 value added/revenue ratio to estimate 1899 value added. For the latter, 1899 Western Union revenues were taken from Carter et al. (2006, series Dg 16). To arrive at non – Western Union revenues the growth of this category relative to Western Union growth has been calculated for 1902-1907. This ratio has been used to extrapolate 1902 non-Western Union revenues back to 1899. The ratio between gross income and value added in the telephone industry for 1902, as reported in Department of Commerce and Labor, Bureau of the Census, Bulletin 17, *Telephones and Telegraphs, 1902* (1905, p. 31), has then been used to arrive at an estimate for 1899 value added.

Post Office value added is taken as the sum of wages and capital income. The ratio of 1909 wages as reported in King (1930, p. 364) to total revenue as reported in Carter et al. (2006, series Dg 181-9) has been used to estimate 1899 wages based on 1899 revenue from Carter et al. (2006, series Dg 181-9). It has then been assumed that income of remunerated capital was about 0.1 from 1899 revenue.

Value added for spectator entertainment has been calculated by extrapolating the benchmark estimate for 1900 gross output from Bakker (2012), using the growth rate of output over the population growth rate between 1900 and 1909, and multiplying by the average fraction of value added over gross output for live entertainment between 1929 and 1941. The latter has been estimated from the NIPA by using the share of live entertainment expenditure in all 'Amusements and recreation except motion pictures' expenditure.

Government value added has been estimated using John Wallis' (2006) estimate for 1902 of government expenditure, compensation of government employees and net interest paid by government and government surplus or deficit, as no estimate for 1899 itself was available (John Joseph Wallis, "Total government expenditure, by character and object: 1902–1995" in Carter et al. (2006), series Ea 14, 52, 53 and 59). All these values were then extrapolated back to 1899 using GDP-growth from Johnston and Williamson (2017), to arrive at an estimate of government value added for 1899. Then the value added of the Post Office for 1899 (see Appendices A1 and B3) was subtracted, to arrive at the government value added used in this paper to estimate the size of the private domestic economy. As a further coherence check of this estimate, the average ratio of government gross fixed capital consumption to government total labour compensation for 1929-1941 was taken from the National Income and Product Accounts, and it has been assumed that a similar ratio existed in 1902 and in the estimated 1899, which yielded an estimate of 1899 government value added as 3.0% of GDP, which was just marginally lower than the original estimate above of 3.1% of GDP, and gives further confidence in that (latter) estimate. In any case, the findings of this paper are not very sensitive to the difference between the two estimates.

A2. Value Added Weights for 1929

Value added for most sectors has been obtained directly from the National Income and Product Accounts as reported in Appendix C. Below we discuss the sectors for which value added could not be obtained directly from this source.

FIRE and wholesale & retail trade have been taken from Carter et al. (2006, series Dh2 and Dh25-6). Construction has been calculated from Abramovitz (1964). Manufactured gas has been calculated from Kuznets (1941, pp. 659-676).

The weight of electric utilities starts from the quantity of electricity sold and its price as reported in Bureau of the Census (1960, series S80-1) to arrive at the value of gross output for 1929. This value was then multiplied by the value added / gross output ratio calculated for ‘electric light & power and manufactured gas’ for 1929 from Kuznets (1941, pp. 659-676).

Natural gas is based on gross output from Gould (1946) multiplied by the ratio of value added to gross output for petroleum and natural gas together for 1929 from Leontief (1953).

Telephone value added has been calculated from Kuznets (1941, pp. 659-670). A second estimate has been made by using the method for calculating telephone value added outlined for 1939 in section 1.3 below. This estimate was slightly less reliable as for the ‘Independent Telephone Companies’ the geometric interpolation of ‘wages and salaries’ versus the use of relative factor incomes to estimate ‘wages and salaries’ yielded two estimates for value added for ‘Independent Telephone Companies’ that were 33% apart. Using the average of these two estimates yields a total estimate of value added for the entire telephone industry that is only one percent higher than the Kuznets estimate. The latter value has therefore been taken.

For the ‘Domestic Telegraph Industry’ the value of intermediate inputs has been calculated by subtracting ‘wages and salaries’ from ‘operating expenses’ taken from Bureau of the Census (1960, p. 484-5, series R53-67). These ‘operating expenses’ do not include ‘net income’ and ‘federal income tax’, so must be approximately the sum of wages and salaries plus intermediate inputs. Capital income is then taken to be ‘operating revenues’ minus ‘operating expenses’. A similar estimate has been made for the ‘‘International Telegraph Industry’ from Bureau of the Census (1960, p. 485-6, series R72-85).

A second estimate for Telegraph was made based on gross output for the domestic and international telegraph industries from the Bureau of the Census (1961, p. 484) multiplied by the ratio of value added to gross output from Kuznets (1941, pp. 659-670). This estimate yields a value that is 2.7% higher. As the former estimate is more precise, that estimate has been taken.

Post Office value added is taken as the sum of wages and capital income. Wages were estimated by taking the ratio of the compensation of postmasters as reported in the *Annual Report of the Postmaster General* (1970, pp. 138-141) to all wages as reported in King (1930, p. 364) for 1925, and establishing that this ratio was fairly stable for 1923-25 (fluctuating between 10.0 and 11.1% of all wages), and then using this ratio to estimate all wages for 1929 based on postmasters’ compensation in 1929. It has then been assumed that income of remunerated capital was about 0.1 from 1929 revenue.

For Spectator Entertainment the value added of motion pictures is taken directly from the National Income and Product Accounts. The value added of live entertainment has been estimated by using the share of live entertainment expenditure in all ‘Amusement and recreation, except motion pictures’ expenditure.

For the government sector, from the National Income and Product Accounts the ‘Compensation of employees, general government, federal, state and local’ (excluding ‘Government enterprises’, which are partially in our sector ‘Post Office’ and partially in our Residual Sector) and the ‘Government consumption of fixed capital', excluding the lines for 'Government enterprises' have been taken to calculate government value added.

A3. Value Added Weights for 1939

Value added for most sectors has been obtained directly from the National Income and Product Accounts as reported in Appendix C. Below we discuss the sectors for which the value added could not be obtained directly from this source.

FIRE and wholesale & retail trade have been taken from Carter et al. (2006, series Dh27 and Dh25-6).

Construction value added has been calculated from Abramovitz (1964).

The weight of electric utilities starts from the quantity of electricity sold and its price as reported in Bureau of the Census (1960, series S80-1) to arrive at the value of gross output. This value was then multiplied by the value added / gross output ratio calculated for 'electric light & power and manufactured gas' for 1939 from Kuznets (1941, pp. 659-676).

Manufactured gas is based the estimate for 1938 in Kuznets (1941) extrapolated to 1939.

Natural gas is based on gross output taken from Gould (1946) multiplied by the ratio of value added to gross output for petroleum and natural gas together for 1939 from Leontief (1953).

For the Bell Telephone Companies, the value of intermediate inputs has been calculated by subtracting 'wages and salaries' from 'operating expenses' taken from Bureau of the Census (1960, p. 481, series R14-27). These 'operating expenses' do not include 'interest expenses' and 'federal income tax', so must be approximately the sum of wages and salaries plus intermediate inputs. Capital income is then taken to be 'operating revenues' minus 'operating expenses' plus 'income from Western Electric Co.', which equals the sum of 'interest expenses', 'federal income tax' and 'net income' (Bureau of the Census 1960: 481, series R14-27). A similar estimate has been made for the 'Independent Telephone Companies' from Bureau of the Census (1960, p. 483, series R28-42), with the difference that 'wages and salaries' are not available for 1939 and had to be estimated. We made two estimates: one using the growth rate of 'wages and salaries' between 1934 and 1941 and estimating a 1939 value by geometric interpolation, and one by using the ratio of the factor incomes for the Bell Telephone Companies for 1939. The estimates for value added using these two different 'wages and salaries' estimates differ by only 1.2%, and the average has been taken. Total value added is then the sum of these estimates.

A second estimate has been made using the value-added estimate in Kuznets (1941, pp. 659-676) for 1938 and multiplying it by the growth rate of operating revenue between 1938 and 1939 for Bell and independent telephone companies taken from Bureau of the Census (1960, p. 481-3, series R14-27 and R28-42). This yields a value added that is 4.8% lower than the above estimate. As the second estimate is an extrapolation and based on less information from the actual year (1939), the first estimate has been taken.

For the 'Domestic Telegraph Industry' the value of intermediate inputs has been calculated by subtracting 'wages and salaries' from 'operating expenses' taken from Bureau of the Census (1960, p. 484-5, series R53-67). These 'operating expenses' do not include 'net income' and 'federal income tax', so must be approximately the sum of wages and salaries plus intermediate inputs. Capital income is then taken to be ‘operating revenues’ minus ‘operating expenses’. A similar estimate has been made for the ‘International Telegraph Industry’ from Bureau of the Census (1960, p. 485-6, series R72-85).

A second estimate was made with the second method used for ‘Telephone’, using the weighted growth rate of operating revenues of the domestic telegraph industry and the international telegraph industry between 1938 and 1939 from Bureau of the Census (1960, p. 484) to extrapolate Kuznets’s value added from 1938 to 1939. Both estimates are very close: the first estimate is only 2.6% higher than the second. Given that this first estimate is based on data from the year itself and not on extrapolations, this first estimate has been taken.

Post Office value added is taken as the sum of wages and capital income. Wages were estimated by taking the ratio of the compensation of postmasters as reported in the *Annual Report of the Postmaster General* (1970, pp. 138-141) to all wages as reported in King (1930, p. 364) for 1925, and establishing that this ratio was fairly stable for 1923-25 (fluctuating between 10.0 and 11.1% of all wages), and then using this ratio to estimate all wages for 1939 based on postmasters’ compensation in 1939. It has then been assumed that income of remunerated capital was about 0.1 from 1939 revenue.

Spectator Entertainment value added has been estimated using the same method and sources as for 1929.

The value added for the government sector has been estimated using the same method and sources as for 1929.

Table A1. *Industry Value Added as percentage of the PDE, United States, 1899-1941.*

Industry	Value added (percentage of the PDE)				
	1899-1919	1909-1919	1919-1929	1929-1941	1899-1941
Farming	13.1	11.4	9.8	8.2	10.5
Metals	0.6	0.6	0.6	0.5	0.6
Anthracite Coal	0.3	0.3	0.3	0.2	0.3
Bituminous Coal	0.7	0.7	0.7	0.7	0.7
Oil and Gas	0.4	0.5	0.7	0.9	0.6
Non-metals	0.4	0.3	0.3	0.2	0.3
Foods*	4.1	3.7	3.3	3.5	3.6
Tobacco	0.9	0.9	0.9	1.2	1.0
Textiles	1.9	1.9	1.9	1.9	1.9
Apparel	1.7	1.5	1.4	1.3	1.4
Leather Products	0.9	0.8	0.6	0.6	0.7
Lumber Products	2.3	1.8	1.3	0.8	1.5
Paper	0.5	0.5	0.6	0.7	0.6
Printing Publishing	1.4	1.6	1.8	1.7	1.6
Chemicals	1.0	1.1	1.2	1.4	1.2
Petroleum, Coal Products	0.6	0.9	1.3	1.3	1.0
Rubber Products	0.2	0.3	0.4	0.4	0.3
Stone, clay, glass	0.7	0.8	0.9	0.9	0.8
Primary Metals	2.7	2.6	2.5	2.4	2.5
Fabricated Metals	1.0	1.3	1.6	1.6	1.4
Machinery Non-Electric	2.3	2.2	2.1	2.0	2.2
Electric Machinery	0.4	0.7	0.9	1.1	0.8
Transport Equipment	1.0	1.4	1.9	2.1	1.6
Furniture	0.5	0.6	0.7	0.7	0.6
Miscellaneous	0.9	0.8	0.7	0.7	0.8
Electric Utilities	0.5	1.2	1.8	2.2	1.4
Manufactured Gas	0.1	0.2	0.2	0.2	0.2
Natural Gas	0.1	0.2	0.2	0.3	0.2
Construction*	5.5	4.9	4.4	3.4	4.5
Wholesale & retail trade*	13.9	13.9	14.0	14.6	14.1
Railroads	6.4	6.1	5.8	4.6	5.7
Local Transit	1.1	1.1	1.0	0.9	1.0
Residual Transport	1.1	1.3	1.4	1.8	1.4
Telephone	0.3	0.5	0.7	0.9	0.6
Telegraph	0.1	0.1	0.2	0.1	0.1
Post Office*	0.5	0.5	0.6	0.6	0.5
FIRE*	4.7	8.2	11.7	11.6	9.2
Spectator Entertainment*	0.4	0.5	0.5	0.6	0.5
Manufacturing	24.9	25.4	25.9	26.2	25.6
Great inventions	19.8	22.1	24.4	26.3	23.3
Aggregate measured sectors	75.1	77.9	80.7	78.8	78.2
Government sector	3.5	4.2	4.8	8.2	5.3
Residual sector	24.9	22.1	19.3	21.2	21.8

Notes: benchmark estimates were made for 1899, 1929 and 1939 based on original sources. The period values were then estimated by linear adjacent-year weighting using mid-interval years, for example: 1899-1909 is 25/30 of the 1899 weight and 5/30 of the 1929 weight; 1909-1919 is the average of the 1899 and 1929 weights, and 1919-1929 is 5/30 of the 1899 weight and 25/30 of the 1929 weight.

* = sector measured in this paper but not by Kendrick. FIRE = Finance, insurance & real estate.

Appendix B. Estimates of TFP Growth for Hard-to-Measure Sectors, 1899-1929

B.1. Construction

Kendrick (1961, pp. 489-498) found that capital was a very small production factor in the construction sector, and therefore he only provided labour productivity estimates. From 1970, precise capital income shares of the U.S. construction sector are available from the EU KLEMS dataset (*EUKLEMS database*, November 2009 release, revised June 2010) which report a very small capital income share of 0.1 of value added in 1970. Abramovitz (1964) also suggests that capital was relatively unimportant in this period. Accordingly, for 1899-1929, we have taken labour productivity growth rates from Kendrick (1961, p. 498) to proxy crude TFP growth for 1899-1909, 1909-1919, and 1919-1929. Crude TFP for the periods to 1929 is adjusted by subtracting labour quality growth (see Table 3 in the main text and Appendix D) to arrive at refined TFP growth.

We have checked this estimate using indices of construction output from Abramovitz (1964, pp. 142-4, Table A1, series 6 for 1899-1915 and series 3 for the period after) and indices of labour input (Ibid., p. 125) to calculate output per person-hour growth (and thus TFP growth) for the period 1899-1929. The resulting growth rate for the 30-year period from 1899-1929 is virtually the same as is obtained from Kendrick's growth rates for the three sub periods (1899-1909, 1909-1919 and 1919-1929).

B2. Wholesale and Retail Trade

Kendrick (1961, pp. 499-506) found that capital was also a very small production factor in the wholesale and retail trade sector and therefore he only provided labour productivity growth estimates prior to 1929. He estimated that the capital income share was about 0.13 in both 1937-1948 and 1948-1953, and considerably less than 0.13 in 1929-1937 (Kendrick 1961, p. 505). Kendrick also estimated that about half of all capital stock in 1929 consisted of inventories (1961, p. 504). Accordingly, for 1899-1929, we have taken the labour productivity growth rates from Kendrick (1961, p. 506) to proxy crude TFP growth for 1899-1909, 1909-1919 and 1919-1929. Crude TFP is then adjusted by subtracting labour quality growth (see Table 3 in the main text and Appendix D) to arrive at refined TFP growth.

B3. Post Office

The growth rates of output and person-hours have been calculated from Kendrick (1961, p. 611), who following established convention, included the Post Office, and government enterprises in general, in the PDE. The growth rate of capital is based on the number of first, second, and third-class post offices in existence at the benchmark years, taken from the *Reports of the Postmaster General* (Washington, D.C., various years). Given that between 1909 and 1925 the share of wages in total revenues ranged between 0.62 and 0.80, as reported in King (1930, p. 364), and given that a substantial part of the capital used consisted of the use of government buildings, the income share of total capital (remunerated capital and unremunerated use of government buildings) has been set at 0.4. Using these assumptions, TFP growth rates have been estimated for 1899-1909, 1909-1919 and 1919-1929. Crude TFP is then adjusted by subtracting the labour quality growth rates for the Post Office reported in Table 3 and Appendix B to arrive at refined TFP growth.

B4. Finance, Insurance and Real Estate (FIRE)

Crude TFP growth has been estimated for 1899-1909, 1909-1919, and 1919-1929 as follows. The growth rate of output has been estimated by creating an index consisting of one quarter of the output growth of financial intermediation, one quarter of the growth of life insurance policies, and one half of the growth of rent. These weights follow those reported for the FIRE sector in Central Statistical Office (1956, pp. 364-5).

The output growth of financial intermediation has been taken from Philippon (2015, appendix). The index used consists of the weighted average of Philippon's level index and 8.48 times Philippon's flow index, using Philippon's scaling factor (8.48) to make the two components comparable. Philippon's series have been taken from the file 'Data Series' for his article published on his website http://pages.stern.nyu.edu/~tphilipp/research.htm (accessed on 8 December 2014).

The value of life policies has been taken from Carter et al. (2006), series Cj715, deflated to real values by using the Bureau of Labor Statistics based Consumer Price Index as reported in Carter et al. (2006), series Cc1. Consumer expenditure on rent was taken from Lebergott (1996), Table A2 and deflated to real values using the residential rents index reported in Carter et al. (2006), series Cc4. The growth rate of labour inputs is based on the number of person-hours reported for 'finance, insurance, real estate' by Kendrick (1961, p. 314). The growth rate of the capital stock is based on FIRE tangible assets in 'Banking, 'Insurance' and 'Miscellaneous' reported in Goldsmith (1958), Tables A1, A7 and A15. Factor shares were estimated from Goldsmith (1958) based on 'employee compensation' and 'non-farm proprietors' compensation' for labour and on 'corporate profits, pre-Tax' and 'net interest' for capital, resulting in a 0.5 share for both factors. Using the EU KLEMS data for 1970 for labour and capital compensation in financial institutions and in real estate (*EUKLEMS database*, November 2009 release, revised June 2010), and weighing each sector by a half, also yields factor incomes of 0.5 each. These rates of crude TFP-growth have then been adjusted by subtracting the labour quality growth rates for the FIRE sector reported in Table 3 and Appendix D to arrive at refined TFP growth.

B5. Spectator entertainment

TFP-growth for spectator entertainment has been estimated following the methods and sources set out in Bakker (2012) for 1900 and 1938, extending the estimates to 1899 and 1941, and now including the three intermediate benchmark years, 1909, 1919 and 1929. The output estimates are based on the consumer expenditure series from Carter et al. (2006, series Dh311 and Dh312), the National Income and Product Accounts, the Bureau of Labor Statistics Admission Price Index, and several other price studies for the period before 1929. The labour estimates are based on the census using the same method as outlined for 1900 in Bakker (2012). Labour quality has been estimated using the method outlined in Appendix D. The capital estimates are based on Bakker (2012), extrapolating the 1900 estimate by one year using a composite growth index of capital proxies to arrive at an 1899 estimate, using the method outlined in Bakker (2012) for 1900 to arrive at the 1909 estimate, and for 1938 to arrive at a 1941 estimate. For motion pictures the annual investments in new cinemas have been used to make an estimate for 1929 based on the 1941 estimate. The 1919 estimate has been interpolated from the 1909 and 1929 estimates using the growth in aggregate cinema seating capacity and the capital per seat deflated by Kuznets' (1961) capital goods deflator. Live capital for 1929, and for 1926 (a year before talking pictures arrived) has been estimated assuming capital grew at one fourth the rate of output (given the small share of live capital by this time, the findings are not very sensitive to this assumption). Live capital for 1919 has been estimated by geometrically interpolating the 1909 and 1926 values. For 1929-1941 the resulting stock-based capital growth rate has been modified to a capital services-based capital growth rate by multiplying by the weighted difference between stock- and service-based capital growth estimates of the ‘Motion picture and sound recording industries’ and ‘Performing arts, spectator sports, museums, and related activities’ from the Bureau of Economic Analysis’ fixed assets table (see Appendix C). A detailed statistical survey from 1909 of all Boston entertainment venues, reported by Jowett (1974), was used to assess the relative importance of live and filmed entertainment at that time.

B6. Foods

We needed to make an adjustment for the Food sector in order to combine Kendrick’s (1961) separate series for crude ‘Food’ TFP-growth and for crude ‘Beverages’ TFP-growth into one aggregate series for crude Food TFP-growth for 1899-1929 which is comparable with the NIPA data for 1929-1941.

From Fabricant (1940: 608-610), the weights for Beverages value added as share of total value added for Food for 1899, 1909, 1919 and 1929 have been taken to compute average weights for 1899-1909, 1909-1919 and 1919-1929. These weights have then been used to merge Kendrick’s separate series of crude TFP-growth. From the resulting rate then has been subtracted the labour quality growth in Food as reported in Table 3 to arrive at refined TFP-growth for Food for 1899-1929 that is comparable with the NIPA data for 1929-1941.

It should be noted that the resulting TFP-growth rate for Food masks two very different trends for ‘Food’ compared to ‘Beverages’ that was visible in the Kendrick crude TFP-growth rates, and this may have been the reason why Kendrick found it necessary to list the sectors separately. The disaggregated data show that TFP-growth in Beverages was massively negative (-5.6% per annum) in the 1910s, almost nil (-0.2% per annum) in the 1920s and massively positive in Kendrick’s 1930s (1929-1937) with 15.2% per annum, while crude TFP for Food shrank with only 0.4% per annum in the 1910s, grew with 5.3% per annum in the 1920s, and grew with only 1.5% per annum in the latter period (Kendrick 1961: 136). Our Foods sector, combining Kendrick’s ‘Food’ and ‘Beverages’, was by far the largest manufacturing sector in all sub periods, ranging from 1.2 - 1.6 times the next largest manufacturing sector. The end of Prohibition coincided with a massive 15.2% per annum growth of Beverages crude TFP between 1929 and 1937, and this clearly had a large pull on manufacturing TFP-growth as a whole.

Appendix C. Measurement and Sources for Output and Input, 1929-41

As emphasized by Field (2003), the assessment of productivity trends during the 1930s is highly sensitive to the choice of beginning- and end-point. In order to prevent cyclical effects from influencing the measurement of productivity growth it is best to choose business-cycle peaks as reference years. Kendrick's (1961) choice of comparing the depressed American economy in 1937 to the peak-year of 1929 conflicts with this principle. Field (2003: 1403) argues instead that 1941, with an unemployment rate of 9.9%, compares much more favourably to the fully employed economy of 1929 than the year 1937 (14.3% unemployment). Regrettably, little productivity data is available – at least not beyond the total economy trends – for the early 1940s. This led Field (2006) to restrict his analysis of technological change between 1929 and 1941 to a 4-sector breakdown of TFP growth. As noted in section 1, however, we require a much finer breakdown in order to fully decompose the sectoral contribution to TFP and labour productivity growth. This appendix describes the methods and sources which we use to develop new, industry level estimates extending beyond Kendrick's original 1929-37 figures. These new estimates allow us to measure productivity growth over the period suggested by Field, 1929-41, while matching the full sectoral detail realized by Kendrick.

Output

Instead of estimating value added on the basis of industry output less purchases of materials and services, we obtain nominal gross value added by summing over total compensation, gross operating surplus, and taxes on production less subsidies. The components of value added at the industry level are compiled by the U.S. Bureau of Economic Analysis (BEA, 2009) and listed in the *National Income and Product Accounts* (NIPA). Table C1 provides an overview of the relevant variables, the exact source-tables, the number of industries differentiated, as well as the share of value added covered by each respective variable in the year 1947.

The NIPA tables provide annual data at the industry level, allowing us to estimate net output for a set of 38 (disaggregate) industries, completely covering the domestic economy. As illustrated in table C1, the NIPA provides full industry coverage for the most influential variables which, together, make up over 80% of gross value added. For the remaining variables the BEA supplies data at a higher level of aggregation, distinguishing between either 12 separate industries (e.g. proprietors' income) or listing the total-economy value only (e.g. taxes on production less subsidies). For these variables, we use the detailed industry-level data for the components of value added in 1947 – taken from the BEA's (2011) *Historical Industry Accounts Data* – to distribute the aggregate figures over our complete list of industries.

To obtain real value added we deflate the nominal output figures for agricultural, mining, manufacturing, utilities and wholesale trade on the basis of wholesale prices compiled by the U.S. Bureau of Labor Statistics (1943: 4; 1949: 6; 1958: 26, 34) supplemented with the production prices listed in the *Historical Statistics of the United States* (HSUS 1975: 582-6) and the price index of electrical equipment compiled by the BEA (2010). For the remaining service sectors, we apply the relevant price indices for personal consumption expenditure from the NIPA (BEA 1966: table 8.6; BEA 2009: table 1.5.4) and Kendrick (1961: 543-5, 556, 583-4). We aggregate the price deflators over industries on the basis of an annually chained Fisher index, where nominal gross value added, previously discussed, serves as weights.

Table C1. *Components of Value Added by Industry, United States, 1929-1941.*

Variable	Description	Source [a]	Cov. [b]	Shr. [c] (%)
VA	Value added, by industry			100
COMP	Compensation of employees, by industry	NIPA, table 6.2A	38	54
TXPIXS	Taxes on production and imports less subsidies	NIPA, table 1.7.5 line 18	1	7
GOS	Gross operating surplus, by industry			
NINT	Net interest, by industry	NIPA, table 6.15A	12	1
PROINC	Proprietors' income, by industry (nonfarm)	NIPA, table 6.12A	12	9
FRMINC	Proprietors' income, farm (with IVA and CCadj)	NIPA, table 2.1 line 10	1	6
PBT	Corporate profits before tax, by industry	NIPA, table 6.17A	38	13
CCCA	Corporate capital consumption allowance, by industry	NIPA, table 6.22A	38	3
NCCA	Non-corporate capital consumption allowance, by industry	NIPA, table 6.13A	12	3
BCTP	Business current transfer payments	NIPA, table 7.7 line 1	1	0
IVA	Inventory valuation adjustment, by industry (nonfarm)	NIPA, table 6.14A	12	-3
CCadj	Capital consumption adjustment, by industry (nonfarm)	NIPA, table 7.6	1	0
GCFC	Consumption of fixed capital, government	NIPA, table 7.5 line 21	1	4
RIP	Rental income of persons, FIRE	NIPA, table 2.1 line 11	1	3

[a] *Source*: BEA (2009).

[b] Number of separate industries distinguished in the original source. Note that full coverage corresponds to 38.

[c] Share of total economy value added covered in 1947. Source: BEA (2011).

Labour input

For labour input we rely on estimates of total employment by industry, fully compensated for changes in the average annual hours of work and the growth in the quality of labour. The sources for total employment and the average hours of work are discussed below. The adjustment for labour quality is dealt with in appendix D.

In correspondence with Kendrick (1961: 47-9), we define total employment as the sum of the number of employees, converted to a full-time equivalent basis, and self-employed persons. From 1929 onwards, the NIPA (BEA 2009: table 6.8A) lists this statistic as the total Persons Engaged in Production (PEP) at the detailed industry level.

Estimates for the average annual hours of work between 1929 and 1941 for the majority of industries are based on Kendrick (1961: 310, 360-2, 397-8, 543-7, 556, 583-4, 590-8, 611). For construction, other transportation and trade we rely on the HSUS (1975: 170-3) estimates of changes in the weekly hours of work. In addition, we accounted for differences in the average hours of work in durable and nondurable manufacturing based on data from the HSUS (1975: 169-70), normalized to fit Kendrick's (1961: 465-6) total manufacturing estimates. Our final measure of labour input is then derived by multiplying total employment (PEP) by both the index for the change in the average annual hours of work as well as the index for labour quality.

Capital input

For the period 1929 to 1941 we estimate the capital input on the basis of capital services. As opposed to capital stocks, which measure the total value, or wealth of all capital equipment and structures in place, our measure captures the capital service *flows* derived from these capital assets. The difference between both these methods is that capital services weight the growth of capital assets by their respective rental prices, whereas capital stocks weight assets by their asset price. As noted by Jorgenson et al. (2008: 109), "[c]apital input takes the form of services of the capital stock in the same way that labour input involves the services of the work force", making the resulting capital service indices strictly comparable to the measure of labour input discussed above.

In comparison to the stock measure, the capital service flows will allocate greater weight to assets that have shorter asset lifetimes and/or rapidly falling asset prices, as both of these characteristics will drive up the cost a user would have to pay to hire the asset for a given period. In the 1930s, prime examples of assets that are underweighted by the traditional capital stock measure are: communication equipment, instruments and trucks.

Our capital services differ from the measure of capital adopted by Kendrick (1961) but is consistent with the post-war estimates of capital input by the BLS. This thus allows us to directly compare the 1929-1941 residual in our growth accounting exercise to the official TFP estimates for the decades following the war.

The construction of the indices of capital services proceeds in two phases. First, we estimate the industry-level stock of capital for the private domestic economy between 1929 and 1941 using a Perpetual Inventory Method (PIM) and the investment series taken from the BEA's *Fixed Assets* tables. Second, we estimate the rental price of assets at the industry level based on the imputed industry rate of return, the asset-specific rate of depreciation and capital gains and losses resulting from changing asset prices. Multiplying the stock of an asset by its rental price yields so called 'capital compensation', which in turn can be used as weights to aggregate the capital stocks to the industry and ultimately the total economy level.

For the construction of the capital stocks, we follow the approach set out by the BEA (2003: M-7), where the real investment ($I_{i,k}$) for asset *k* during year *i* is assumed to contribute $N_{i,k,t}$ to the real net stock of capital at the end of year *t*.

$$N_{i,k,t} = I_{i,k}\left(1 - \frac{\delta_k}{2}\right)(1-\delta_k)^{t-i} \quad \text{, where } t \geq i \tag{C.1}$$

All investments are expected to have been made during the middle of the calendar year and are depreciated at an annual geometric rate of depreciation δ_k. By summing the contributions over all investments up to and including year *t*, the real net stock of capital ($N_{k,t}$) for asset *k* at the end of year *t* can be derived.

$$N_{k,t} = \sum_{i=1}^{t} N_{i,k,t} \tag{C.2}$$

From 1901 onwards, the BEA's (2010) detailed *Fixed Assets* tables provide annual industry-by-asset investment series for private nonresidential capital. To reliably estimate the starting stock of capital in 1900, we supplement this data with the asset-specific constant-cost investment series for the period 1832-1900, listed in the BEA's (1993: 374-81) *Fixed Reproducible Tangible Wealth* report. Unfortunately, the pre-1901 investment series is only available at the total private economy level. We thus distribute the nineteenth century investment data for each of the 37 assets over our entire industries-list on the basis of the average investment shares for the first decade in the twentieth century – for which we have detailed industry-by-asset data. The geometric rates of depreciation for all our assets, with the exception of automobiles, are taken from Fraumeni (1997). The rate of depreciation for autos was derived implicitly from the standard *Fixed Assets* tables (BEA 2010, tables 2.2, 2.8).

On the basis of these investment series, depreciation estimates and equation (C.2) we compile the real net stock of capital between 1929 and 1941 for all assets and industries distinguished by the BEA (with the exception of the government sector). Capital services (*K*) for industry *j* can then be derived by weighting the growth of capital stocks for all *m* assets by its relative share in total industries capital compensations (φ). Dropping the industry subscript *j* for ease of notation, the growth of capital services can be represented as

$$\widehat{K} = \sum_{k=1}^{m} \overline{\varphi}_k \widehat{N}_k \tag{C.3}$$

Where hats indicate growth rates in natural logs and $\overline{\varphi}_k$ is the average share of capital compensation in year *t* and *t-1* for asset *k*

$$\overline{\varphi}_k = \frac{1}{2}\left(\varphi_{k,t} + \varphi_{k,t-1}\right) \tag{C.4}$$

As noted previously, capital compensation is the product of the rental price ($p^K_{k,t}$) and the real stock ($N_{k,t}$) of this asset. The share (φ_k) is then calculated by dividing the assets capital compensation by the total industry's capital compensation. Note that industry *j's* capital compensation can be obtained from the national accounts as gross operating surplus (GOS) minus the sum of noncorporate income not allocated to labour (see table C1).

$$\varphi_k = \frac{p^K_{k,t} N_{k,t}}{\sum_{k=1}^{m} p^K_{k,t} N_{k,t}} \tag{C.5}$$

The calculation of the rental price reflects the fact that in equilibrium, an investor is indifferent between two alternatives: either buying a unit of capital at time t-1, collecting a rental fee and then selling the depreciated asset in the next period, or earning a nominal rate of return on a different investment opportunity. The capital services thus depend on the asset-specific depreciation rates (δ_k), the (industry-specific) rate of return (i_t) and the capital gains or losses from changes in the asset-specific investment price ($\hat{p}^I_k$).[21]

$$p^K_{k,t} = p^I_{k,t-1} i_t + p^I_{k,t}\delta_k - \frac{1}{2}\left(\hat{p}^I_{k,t-1} + \hat{p}^I_{k,t}\right) p^I_{k,t-1} \tag{C.6}$$

For the calculation of the industry rate of return we follow the ex-post procedure preferred by the BLS to make our capital service estimates comparable to the post-war figures. The rate of return is the sum of total capital compensation and the total capital gains from changes in investment prices, minus total depreciation, divided by the capital stock in prices of year *t-1*.

$$i_t = \sum_{k=1}^{m}\left(p^K_{k,t} N_{k,t} - p^I_{k,t}\delta_k N_{k,t} + \tfrac{1}{2}\left[\hat{p}^I_{k,t-1} + \hat{p}^I_{k,t}\right] p^I_{k,t-1} N_{k,t}\right) \Big/ \sum_{k=1}^{m} p^K_{k,t-1} N_{k,t} \tag{C.7}$$

For the estimation of the rental prices we again rely on Fraumeni's (1997) depreciation rates, the BEA's (2010) price index of investment and the industry-level capital compensation from the NIPA tables (BEA 2009).

Table C2 shows the difference between Kendrick's original capital input measures, the average annual growth of the capital stock measured using the BEA's investment series and the growth in capital services. Kendrick's estimates are very similar to the growth figures for the capital stocks but differ substantially from the estimates based on capital services. As previously noted, capital service flows will allocate greater weight to assets that have shorter asset lifetimes (e.g. instruments, machinery and trucks), the stock of which expanded more rapidly than for long-lived assets (i.e. structures and long-lived equipment such as ships and train rolling stock) during the 1930s. This explains why the growth figures for capital services exceed the capital stock-based measures for both the PDE and PNE as well as most of the underlying industries during the years 1929-1941.

[21] In equations (C.6) and (C.7) we rely on the two-period average change in the asset-specific investment prices to smooth out incidental price shocks. The subscript *t* refers to growth between year t-1 and t.

Table C2. *Average Annual Rates of Growth of Capital Input, United States, 1929-1941, in percent per annum.*

Economic Aggregate	Annual growth (% per annum)
Private domestic economy (PDE)	
Kendrick	-0.08
Capital stocks	-0.09
Capital services	0.37
Private domestic nonfarm economy (PNE)	
Kendrick	-0.13
Capital stocks	-0.05
Capital services	0.48

Source: Kendrick (1961), pp. 333-335; 338-340.

Table C3 shows the impact that the different measures of capital input have on total factor productivity. With the exception of Residual transport, for all industries capital-service based TFP-growth was lower or equal than the stock-based estimates (first three columns). The difference in TFP-growth ranged from minus 0.5 percentage points for metal mining, to plus 0.3 percentage points for Residual transport. Of the aggregate growth rates, only the residual sector (minus 0.4 percentage points), and the PDE-growth rate (minus 0.1 percentage points) were affected. The mean industry TFP-growth decreased by 0.1 percentage point. The coefficient of variation and the range only increased marginally.

The capital services-based intensive growth contribution (IGC) showed a similar pattern (Table C4, first three columns), with only Residual transport having a positive difference, of 0.005% per annum, and the minimum value being -0.014% per annum for Wholesale & retail trade. In the aggregate, the manufacturing IGC decreased with 0.006%, the aggregate measured sectors' IGC with minus 0.030%, the residual sector with minus 0.077%, and the PDE with 0.107%. The mean and coefficient of variation decreased marginally, and the range decreased by 0.013%. Overall, the use of capital-services based TFP-growth and IGC showed a small but not insignificant difference with capital-stock based TFP growth.

For the whole period 1899-1941, using stock-based estimates for 1899-1929 and service-based estimates for 1929-1941, the differences in TFP-growth were very small, and differed in only six sectors from 0.0, ranging from minus 0.1 to 0.1. Likewise, for the IGC there were only significant differences (in the third decimal) for six industries.[22]

Variable retirement

Gordon (2016: 659-663) argues that the official investment and depreciation rates from the BEA severely underestimate the growth in capital input for the period between 1925 and 1945. In particular, he questions whether the depreciation rates, which are fixed over time, are representative for the Depression era. As investment collapsed, Gordon would expect equipment and structures to be scrapped and depreciated at a slower rate; i.e. he proposes that the expected life-time of all assets should increase substantially during the 1930s. This lower rate of depreciation would lead to a greater increase in the capital stock than the estimates by the BEA would suggest.

As a crude proxy for these varying rates of depreciation, Gordon suggests comparing the ratio of investment to the official capital stock for each year with the average for 1925-1972. A low ratio, as was the case for 1933, would indicate an increase in the asset lifetime, whereas a relatively high ratio would indicate a reduction in the time producers hold on to their ageing capital assets.

As a robustness check to our capital input estimates, we apply the same procedure. We estimated the ratio of investment to stock separately for equipment capital and structures. The data was taken from the BEA's (2010) *Fixed Assets*, basic tables 2.1, 2.2, 2.7 and 2.8, lines 3 and 37. The

[22] The tabulated results are available from the authors.

official depreciation rates discussed in the previous section were multiplied by the ratio of investment to capital in the respective year, relative to the average of the period 1925-1972. On the basis of these depreciation rates we re-estimated the capital stocks and capital services. Tables C3 and C4 show the resulting TFP and IGC based on these revised capital inputs.

The effect of the adjustment on industry TFP-growth for 1929-1941 was negligible or significantly negative for all industries. It varied substantially, from 0.0 percentage-points for Coal Mining, Electric Machinery and Furniture, to minus 0.7 percentage-points for Oil & Gas mining and minus 0.5 percentage-points for both Metal Mining, and Petroleum & Coal products. The overall effect on the TFP-growth rate of the PDE was substantial, minus 0.2 percentage-points, which constitutes a ten percent downward adjustment. The impact on the intensive growth contribution (IGC) was small but significant for many industries, as only 7 industries had no difference at three decimals, and the change in the IGC was substantial for Farming, Foods, Wholesale & Retail trade and FIRE—all large sectors. For both TFP and IGC, the mean decreased and the coefficient of variation increased by about ten percent.

For the whole period 1899-1941, using standard depreciation-based estimates for 1899-1929 and variable retirement-based estimates for 1929-1941, the differences in TFP-growth were very small, minus 0.1 or 0.0 in most sectors and minus 0.2 in only one sector, Oil & Gas. Likewise, for the IGC there were only marginally significant differences (in the third decimal) for 19 industries and no significant differences in 17 industries.[23]

Electrical equipment

To estimate the share of electrical equipment assets in the total stock of equipment – used to measure the impact of the installed electrical horsepower in manufacturing in section 6 – we also compile an annual series of the nominal net stock of capital for electrical equipment and total equipment. We apply the methods described above but focus on the period 1921 to 1929 instead.[24] The nominal net stock of electrical equipment is the aggregate of the nominal value of the BEA (2010) assets EI60 (electrical transmissions, distribution and industrial apparatus) and EO70 (electrical equipment not elsewhere classified). Total equipment includes electrical equipment in addition to transportation equipment, instruments and non-electrical equipment. We estimate the share of electrical equipment assets by dividing the nominal stock of electrical equipment by the total stock of equipment for the years 1921 and 1929 and then taking the average over both these years.

[23] The tabulated results are available from the authors.

[24] Note that the shorter asset lifetimes for machinery and equipment allows us to safely estimate the real and nominal stocks for these assets beginning in 1921. The greater rate of depreciation reduces the sensitivity of these assets to the assumptions made regarding the pre-1900 rate of investment by individual industries.

Table C3. *Comparative growth in Total Factor Productivity (TFP) by industry, using capital stock vs. capital services and standard depreciation vs. variable retirement, United States, 1929-1941.*

Industry	TFP-growth (percent per annum)					
	Effect capital services			Effect variable retirement		
	Stock	Serv.	Diff.	SD	VR	Diff.
Farming	2.6	2.5	-0.1	2.5	2.2	-0.3
Metals	1.1	0.6	-0.5	0.6	0.1	-0.5
Anthracite Coal	0.4	0.3	0.0	0.3	0.3	0.0
Bituminous Coal	1.9	1.8	-0.1	1.8	1.8	0.0
Oil and Gas	2.1	2.1	0.0	2.1	1.3	-0.7
Non-metals	3.9	3.6	-0.3	3.6	3.3	-0.3
Foods*	3.7	3.7	0.0	3.7	3.5	-0.2
Tobacco	5.8	5.8	-0.1	5.8	5.3	-0.5
Textiles	3.4	3.3	-0.1	3.3	3.1	-0.2
Apparel	-0.4	-0.4	0.0	-0.4	-0.5	-0.1
Leather Products	-0.1	-0.1	0.0	-0.1	-0.2	-0.1
Lumber Products	-1.7	-1.7	0.0	-1.7	-1.9	-0.1
Paper	1.2	1.1	-0.1	1.1	1.0	-0.1
Printing Publishing	0.3	0.3	0.0	0.3	0.2	-0.1
Chemicals	2.2	2.1	0.0	2.1	1.9	-0.2
Petroleum, Coal Products	-1.2	-1.1	0.1	-1.1	-1.6	-0.5
Rubber Products	1.6	1.5	-0.1	1.5	1.4	-0.1
Stone, clay, glass	1.9	1.7	-0.1	1.7	1.5	-0.2
Primary Metals	2.3	2.3	0.0	2.3	2.0	-0.3
Fabricated Metals	1.3	1.3	0.0	1.3	1.2	-0.1
Machinery Non-Electric	2.1	2.2	0.1	2.2	2.0	-0.2
Electric Machinery	4.6	4.7	0.1	4.7	4.6	-0.1
Transport Equipment	3.6	3.6	0.0	3.6	3.4	-0.2
Furniture	1.4	1.4	0.0	1.4	1.4	-0.1
Miscellaneous	1.7	1.6	-0.1	1.6	1.4	-0.2
Electric Utilities	5.2	5.2	0.0	5.2	4.7	-0.4
Manufactured Gas	2.0	2.0	0.0	2.0	1.7	-0.3
Natural Gas	3.8	3.8	0.0	3.8	3.4	-0.4
Construction*	0.4	0.3	0.0	0.3	0.3	-0.1
Wholesale & retail trade*	3.5	3.4	-0.1	3.4	3.3	-0.1
Railroads	2.5	2.6	0.0	2.6	2.4	-0.1
Local Transit	0.5	0.4	-0.1	0.4	0.2	-0.1
Residual Transport	5.5	5.6	0.1	5.6	5.6	0.0
Telephone	1.3	1.4	0.1	1.4	1.1	-0.2
Telegraph	0.8	0.9	0.0	0.9	0.7	-0.1
Post Office*	0.6	0.8	0.1	0.8	0.4	-0.3
FIRE*	-1.3	-1.4	0.0	-1.4	-1.8	-0.4
Spectator Entertainment*	4.4	4.4	0.0	4.4	4.4	0.0
Great Inventions*	3.2	3.2	-0.1	3.2	3.0	-0.2
Aggregate measured sectors	1.8	1.7	0.0	1.7	1.5	-0.2
Residual sector	2.7	2.3	-0.4	2.3	2.3	0.0
PDE	2.0	1.9	-0.1	1.9	1.7	-0.2
Memorandum:						
Kendrick's aggregate measured sectors	2.5	2.5		2.5	2.5	
Kendrick's residual sector	2.0	2.0		2.0	2.0	
Kendrick PDE	2.3	2.3		2.3	2.3	

Minimum	-1.7	-1.7	0.0	-1.7	-1.9	-0.1
Maximum	5.8	5.8	-0.1	5.8	5.6	-0.2
Range	7.5	7.5	0.0	7.5	7.5	0.0

Notes: **Stock** = TFP-growth rate is calculated from input data that include stock-based estimates of capital. **Serv**. = TFP-growth rate is calculated from input data that include service-based estimates of capital. **Diff**. = the difference between the rates in the two preceding columns. **SD** = TFP-growth rate is calculated from input data based on the standard depreciation method using capital services set out in this appendix. **VR** = TFP-growth rate is calculated from input data based on using both capital services (as set out in this appendix) and the variable retirement of capital method introduced by Gordon (2016). Kendrick's aggregate measured sector comprises Farming, Mining, Manufacturing, Transportation, Communication & Public Utilities). ***** = sector measured in this paper but not by Kendrick. For 1929-1941 and 1899-1941 the TFP-growth of Kendrick's measured and residual sectors was estimated using our data for Kendrick's measured sectors for 1929-41 and the relationship between measured, residual and aggregate TFP growth in Kendrick's numbers for his 4 sub-periods during 1899 through 1937. TFP here is refined TFP, i.e. after correcting crude TFP for the growth of labour quality (see text).
Source: Kendrick 1961, pp. 136-7; own calculations, see the text and Appendices B, C and D.

Table C4. *Comparative intensive growth contribution by industry, using capital stock vs. capital services and standard depreciation vs. variable retirement, United States, 1929-1941.*

Industry	Intensive Growth Contribution (VA share x TFP growth)					
	Effect capital services			Effect variable retirement		
	Stock	Serv.	Diff.	SD	VR	Diff.
Farming	0.212	0.206	-0.006	0.206	0.179	-0.027
Metals	0.006	0.003	-0.003	0.003	0.001	-0.003
Anthracite Coal	0.001	0.001	0.000	0.001	0.001	0.000
Bituminous Coal	0.013	0.013	0.000	0.013	0.012	0.000
Oil and Gas	0.018	0.018	0.000	0.018	0.012	-0.006
Non-metals	0.008	0.008	-0.001	0.008	0.007	-0.001
Foods*	0.132	0.131	-0.001	0.131	0.123	-0.008
Tobacco	0.067	0.067	-0.001	0.067	0.061	-0.005
Textiles	0.063	0.062	-0.001	0.062	0.058	-0.004
Apparel	-0.005	-0.006	0.000	-0.006	-0.007	-0.001
Leather Products	0.000	0.000	0.000	0.000	-0.001	-0.001
Lumber Products	-0.014	-0.014	0.000	-0.014	-0.015	-0.001
Paper	0.008	0.008	0.000	0.008	0.007	-0.001
Printing Publishing	0.005	0.005	0.000	0.005	0.003	-0.002
Chemicals	0.031	0.030	-0.001	0.030	0.027	-0.004
Petroleum, Coal Products	-0.015	-0.014	0.001	-0.014	-0.020	-0.007
Rubber Products	0.007	0.007	0.000	0.007	0.006	0.000
Stone, clay, glass	0.017	0.016	-0.001	0.016	0.014	-0.002
Primary Metals	0.054	0.054	0.000	0.054	0.048	-0.006
Fabricated Metals	0.021	0.021	0.000	0.021	0.019	-0.002
Machinery Non-Electric	0.042	0.044	0.002	0.044	0.041	-0.003
Electric Machinery	0.049	0.050	0.001	0.050	0.049	-0.001
Transport Equipment	0.078	0.078	-0.001	0.078	0.073	-0.005
Furniture	0.010	0.010	0.000	0.010	0.009	0.000
Miscellaneous	0.011	0.010	-0.001	0.010	0.009	-0.001
Electric Utilities	0.112	0.112	0.000	0.112	0.102	-0.009
Manufactured Gas	0.004	0.004	0.000	0.004	0.003	-0.001
Natural Gas	0.013	0.013	0.000	0.013	0.012	-0.001
Construction*	0.013	0.012	-0.001	0.012	0.009	-0.003
Wholesale & retail trade*	0.509	0.494	-0.015	0.494	0.483	-0.011
Railroads	0.118	0.119	0.000	0.119	0.112	-0.007
Local Transit	0.004	0.003	-0.001	0.003	0.002	-0.001
Residual Transport	0.097	0.099	0.002	0.099	0.099	-0.001
Telephone	0.012	0.012	0.001	0.012	0.010	-0.002
Telegraph	0.001	0.001	0.000	0.001	0.001	0.000
Post Office*	0.004	0.005	0.001	0.005	0.003	-0.002
FIRE*	-0.156	-0.158	-0.003	-0.158	-0.207	-0.049
Spectator Entertainment*	0.025	0.025	0.000	0.025	0.025	0.000
Great Inventions*	0.851	0.836	-0.015	0.836	0.789	-0.047
Aggregate measured sectors	1.405	1.375	-0.029	1.375	1.198	-0.178
Residual sector	0.569	0.485	-0.083	0.485	0.481	-0.005
PDE	1.974	1.861	-0.113	1.861	1.679	-0.182
Mean	0.041	0.041	-0.001	0.041	0.036	-0.005
Coefficient of variation	2.290	2.283	-0.007	2.283	2.584	0.301
Minimum	-0.156	-0.158	-0.003	-0.158	-0.207	-0.049

Maximum	0.509	0.494	-0.015	0.494	0.483	-0.011
Range	0.665	0.653	-0.013	0.653	0.690	0.038

Notes: see table C3.

Source: see table C3.

Appendix D. Labour Quality

D1. Discussion of the Kendrick Labour Quality Estimates

Kendrick (1961: 31-34) assessed the effect of skill changes on the composition of the labour force between 1869 and 1957. Instead of measuring changes in education attainment, gender and experience directly, however, he measured the changes in the occupational structure. He adjusted labour input by weighting the person-hours of work in separate occupations and industries by their average hourly earnings for a given base year. Kendrick's measure of labour quality thus captures two effects: (1) the relative shifts of workers between occupations, and (2) the relocation of employment between industries. The first effect, the shift of workers from low-paying positions (e.g. laborers) to better-paying jobs (e.g. operatives or clerical staff), reflects a change in the potential output per worker. The higher earnings (measured in terms of base-period compensation) imply a rise in the marginal productivity of that worker and thus a rise in the quality of the labour force – in line with the Jorgenson approach discussed below. Likewise, the shift of workers to better-paying industries also show up as an increase in labour quality.

Kendrick assumes under (1) that labour quality will only change over time if a worker transfers from one occupation to another or if an individual joins (or leaves) the labour force in an occupation that is better (worse) paid than the national average. Kendrick (1961: 33) surmises that "the inherent average physical and mental capacity of the person employed in each occupation is constant over time." The rapid increase in educational attainment during the late nineteenth and early twentieth century casts serious doubt on this assumption, however. The average years of schooling for cohorts born between 1880 and 1950 nearly doubled, increasing from approximately 8 to 14 years (Goldin and Katz, 2008: 20; 113; 170). Part of this increase in skill translated into a shift of employees between occupations and industries, but part also translated into a rise of the labour quality *within* occupations. For instance, the likelihood for a blue-collar worker born around 1885 to have attended high school was substantially greater than it was for its counterpart born only 10 years prior, around 1875. The high-school education gave the blue-collar worker basic knowledge of chemistry, electricity and algebra, allowed him to read manuals and blueprints and made it much easier for him to effectively converse with managers and other professionals, raising his marginal productivity in the process. In addition to undervaluing the impact of the rapid increases in education attainment during the late nineteenth and early twentieth century, Kendrick's method ignores other demographic changes as well which thus biases his labour quality figures downwards compared to our own (see table D1). Changes in the educational attainment, average age, or experience of the workforce and shifts in the gender composition are generally considered to be determining factors in the quality of labour, as we will illustrate below.

Table D1. *Average Annual Rates of Growth of Labour Quality, United States, 1899-1941, percent per annum*.

	Kendrick	This study
Private domestic economy (PDE)	0.32	0.79
1899-1929	0.36	0.87
1929-1941	0.20	0.59
Private domestic nonfarm economy (PNE)	0.15	0.36
1899-1929	0.16	0.40
1929-1941	0.14	0.27

Source: Kendrick (1961), pp. 333-335; 338-340; this paper.

D2. Discussion of the Labour Quality Estimates in this Paper

In order to fully assess the impact of the substantial investments in schooling as well as the structural changes in the gender and age composition of the American workforce during the early twentieth century, we turn to an approach developed by Dale Jorgenson and Zvi Griliches (1967). The key innovation in their work was to adjust the traditional measure of labour input – i.e. total hours of work – for improvements in quality. The main principle behind the labour quality adjustment is the distinction among several different types of labour inputs characterized by one or more quantifiable factors that affect the productivity potential of the worker (e.g. educational attainment, age, gender). By then assigning weights to these categories – usually in the form of average wages and earnings – one can measure the change in the productivity 'potential' of the workforce. The rationale for this procedure is that differences in average earnings between the labour categories can be thought of as reflecting differences in their marginal productivity. When this new measure of labour input is used in a growth accounting framework, output growth as a result of better educated and trained workers is ascribed to input growth, rather than productivity or technology growth (Jorgenson et al., 2008). Previous studies have shown that this quality adjusted measure can account for a substantial part of the residual or Total Factor Productivity (TFP) growth within traditional growth accounting studies (Denison, 1962; Griliches, 1963; Denison and Poullier, 1967; Gordon, 2010). Therefore, the labour quality adjustment allows for a purer measure of both labour input as well as technical change within a growth accounting framework.

Methodology

To construct an index of labour input for each individual sector, we assume that labour input ($L_{j,t}$) for industry *j* at time *t* can be expressed as a translog function of its individual components (Jorgenson et al., 1999: 92-3). We form indices of labour input from data on hourly employment by industry (H), cross-classified by gender, age and education.[25] Dropping the industry subscript *j* for ease of notation, the growth of labour input (log growth denoted by a hat) for industry *j* can thus be represented as

$$\hat{L} = \sum_{l=1}^{q} \bar{\mu}_l \hat{H}_l \tag{D.1}$$

where H_l is total hours of work at the industry level for a given set of *q* characteristics of the labour force *l* (gender, age and education) and $\bar{\mu}_l$ is the two-period average of this employment group's share in the total labor income at the industry level.

$$\bar{\mu}_l = \frac{1}{2}\left(\mu_{l,t} + \mu_{l,t-1}\right) \tag{D.2}$$

The share of labour income ($\mu_{l,t}$) at time *t* is derived as the product of the average hourly wage ($p_{l,t}^L$) and hours of work ($H_{l,t}$) for each combination of labor characteristic *l,* divided by the total wage sum

$$\mu_l = \frac{p_{l,t}^L H_{l,t}}{\sum_{l=1}^{q} p_{l,t}^L H_{l,t}} \tag{D.3}$$

Alternatively, the index of labour input can also be expressed as the product of total hours (H) and an index of labour quality (Q) or, in growth terms, as

$$\hat{L} = \hat{H} + \hat{Q} \tag{D.4}$$

[25] Note that age, in our estimate for labour input, serves as a proxy for (work) experience. We thus assume that an individual has held a job his entire life since leaving high-school or college; depending on his educational attainment.

Rearranging terms in equation (D.4) and substituting the index for labour input by (D.1) we arrive at a direct measure of sectoral labour quality growth

$$\hat{Q} = \sum_{l=1}^{q} \bar{\mu}_l \hat{H}_l - \hat{H} \tag{D.5}$$

The change in labour quality thus reflects the difference between the growth rates of the compensation-weighted index of labour input and sectoral employment.

The drawback of this approach is that it requires highly disaggregate data on hourly employment and compensation, generally not available in the published census reports or secondary sources for the early twentieth century. Fortunately, the Integrated Public Use Microdata Series (IPUMS) has made samples from the decennial population censuses publicly available, providing detailed records for nearly 10 million individuals between 1900 and 1950 (Ruggles et al, 2010). We utilize the microdata from this source to construct our measure of labour quality.

Rather unfortunately, the 1900-1930 American population censuses did not inquire into the educational attainment of the general population, the compensation of workers and employees, nor the average hours of work. To overcome these data issues, we follow a three-tiered approach to the data preparation for the labour quality estimation. First, we estimate educational attainment at the micro level for the pre-1940 census samples on the basis of the 1940 returns. Second, we construct an employment matrix for the entire period that groups workers according to their (predicted) educational attainment, gender, age and by industry. Lastly, we derive the compensation matrix on the basis of average hourly wages for each labour category taken from the 1940 census of population.[26] These employment and compensation matrices can then be used to calculate labour quality on the basis of equation (D.5).

Educational attainment

For the first stage, we estimate the educational attainment *y* for an individual *i* on the basis of his or her occupation, gender, age and place of residence (x_i). This approach takes both the long-run changes in the average years of schooling as well as the effects of changes in the occupational structure and the gender/age composition of the workforce into account. We define four education categories (see table D2) and we predict the likelihood that an individual *i* belongs to each of these specific educational categories (e.g. $Pr\{y_i = 1\}$). This probability should be bounded by 0 and 1, continuous and nonlinear; conditions which are all met by an (ordered) logit model

$$Pr\{y_i \leq k|x_i\} = \frac{e^{x_i'\beta}}{1 + e^{x_i'\beta}} \quad \text{, where } k = 1,2,3 \tag{D.6}$$

The right-hand side of equation (D.6) is a cumulative distribution function with mean 0 and standard deviation 1. The coefficients are estimated using maximum likelihood, which is the optimal parametric estimator in this context (Long and Freese 2006).[27]

[26] The 1940 census was the first census of its kind to ask about schooling, labour compensation and working hours to all citizens surveyed. In the wake of the depression the 1940 population census dedicated a substantial part of its inquiry into the issue of employment and productivity. Note that for the estimation of labour quality we assume the average hours of work per employment category to remain unchanged relative to 1940.

[27] Note that we estimate the cumulative probability for the first three educational categories, since all individuals that are not part of either the first, second or third category will be part of the fourth category. The fourth category can thus be implicitly derived and should be excluded from the model.

Table D2. *Categorical Variables Logit and Labor Quality Models.*

Logit model	Labor quality model
Education:	Education:
See labor quality model	(1) 1-4 years grade school
	(2) 5-8 years grade school
Gender:	(3) 1-4 years high school
See labor quality model	(4) 1 or more years college
Occupation:	Gender:
(1) professional, technical	(1) male
(2) farmers (owners and managers)	(2) female
(3) managers, officials, and proprietors	
(4) clerical staff	Age:
(5) sales workers	(1) 16-17 years
(6) craftsmen	(2) 18-24 years
(7) operatives	(3) 25-34 years
(8) service workers (household)	(4) 35-44 years
(9) service workers (other)	(5) 45 years and over
(10) laborers	
(11) unemployed/retired	Industry:
	See main text
Region:	
(1) South	
(2) Midwest	
(3) West	
(4) Northeast	

Data

For the estimation of the logit model we rely exclusively on the 1940 1-percent sample included in the IPUMS dataset. This sample is limited to include only those citizens aged 16 years and above, leaving approximately 975,000 observations for the logistic regression. The dataset includes a measure of the highest year of schooling or degree completed. As illustrated in table D2, we reclassify this variable to encompass four distinct educational attainment classes. The reason we reclassify the education variable is twofold. First, by treating it as a categorical variable as opposed to a continuous variable (e.g. years of education), we avoid the assumption that the distances between classes are equal; i.e. that an additional year of grade school is identical to one additional year in college. Second, we limit the number of classes to 4 to ensure that each class is covered by a sufficient number of observations. This is important not just for the estimation of educational attainment, but also for the construction of the compensation matrix.[28] For the independent variables, we follow the literature on US labour quality and mark four variables as important predictors of educational attainment, namely: occupation, birth cohort, gender and region.

Individuals are classified into one of eleven main occupational groups which differ markedly in terms of their average educational attainment. For instance, the probability of a professional (e.g. engineers, economists) having attended high school was substantially greater than was the case for the average labourer. The importance of gender and year of birth is illustrated by Goldin and Katz (2008: 18-22; 170). They observe a rapid increase in the average years of schooling throughout the late nineteenth and early twentieth century. Each successive cohort spent a substantially greater number of years in school compared to the previous generation. In addition, Goldin and Katz (2008: 19) show that women generally attended school for longer than men did throughout most of the early twentieth century. The gender variable was taken directly from the IPUMS dataset while the year of birth was rounded to the

[28] Limiting the number of classes for the education variable allows us, for instance, to test the 'parallel regression assumption'; meaning that for each education class (grade-school, high-school, college, etc.) the coefficients for the independent variables (beta) are identical. As it turns out the assumption is violated. Hence, we effectively estimate separate regressions for all education classes, obtaining different betas for each.

nearest decade. The log of the relative distance in decades to 1930 was then taken as the birth cohort measure. Lastly, the literature points to widespread differences in state support for education and shows that the rise in both high school graduation rates as well as college enrolment rates for states in the North and West of the country were considerably more impressive than for the rest of the nation (Goldin and Katz, 2008: 271-7). We incorporate a variable in the model that differentiates between the four main regions of the country (see table D2).

For the second stage of the labour quality estimation, the construction of the employment matrix, we rely on the IPUMS 1-percent census samples for the decades between 1900 and 1950. To estimate educational attainment we include the occupation, birth cohort, gender and region variables discussed earlier, supplemented by data on the age of the individual, number of weeks worked in the previous year, the average hours of work per week, and industry in which the subject is engaged. The employment sample is limited to include only those citizens between the ages of 16 and 84, who are part of the labour force. For the employment-matrix our dataset includes roughly 3,135,000 individual observations.

In the third stage of the data preparation we again rely on the 1940 sample to estimate relative hourly compensation per labour category. Here we limit the sample to include only those citizens between the ages of 16 and 84 having worked at least 48 weeks in the previous year and earning an income greater than 0 (Goldin and Katz, 2008). These individuals are allocated to the cells of the matrix cross-classified by gender, age, education and industry as summarized in table D2. Compensation is reported in the census as the respondent's total pre-tax wage and salary income for the previous year, expressed in current dollars. To obtain total personal income, which also includes non-wage income, we multiplied the 1940 compensation figures by the industry specific ratio between wage and salary income and total personal income taken from the 1950 census returns. Nonwage income generally represented only a small part of total personal income, with the notable exception of the agricultural sector. The samples for the logistic regression, the compensation matrix and the employment matrix are all weighted by the IPUMS `person weight' variable.

Robustness

Ideally, we would like to allow the weights for our labour quality index to vary over time, reflecting potential changes in relative compensation between the labour categories. Unfortunately, the censuses prior to 1940 did not inquire into either wages or earnings, impeding the accurate measurement of labour compensation for these earlier decades. Reassuringly, Goldin and Katz (2008: 53-63) demonstrate that the wage structure observed in 1940 was fairly typical for the pre-war period. Although they do observe a gradual compression of the wage distribution for production workers between 1890 and 1940, Goldin and Katz conclude that the gap in the skilled/unskilled wage level for 1920 was virtually identical in comparison to 1940.

On the basis of Goldin and Katz's (2010) data for the state of Iowa we can perform a more conclusive sensitivity check of our labour quality figures. The *Iowa State Census Project* provides detailed compensation data, cross-classified by most of the categories that make-up labour input for the year 1915. Below we will compare the results from the third stage of the data preparation – the estimation of the compensation matrix – for the 1915 Iowa data and the original 1940 census data. We will then use these new estimates to provide an alternative estimate of labour quality for the first half of the twentieth century and decompose these estimates to trace the sources of divergence. In addition, we perform the same sensitivity check based on comprehensive income data for 1950, taken from the IPUMS dataset. Overall, on the basis of this evidence presented here, we feel confident using solely the 1940 compensation figures as weights for the construction of our labour quality index.

Table D3. Labour Income Estimates for Iowa and the United States, 1915, 1940 and 1950, Dependent Variable: Log of Labour Income

	US 1940 (1)	US 1940 (2)	Iowa 1940 (3)	Iowa 1915 (4)	US 1950 (5)
Intercept	6.82***	6.90***	6.64***	6.48***	7.54***
	(0.005)	(0.003)	(0.029)	(0.012)	(0.009)
Female dummy	-0.70***	-0.53***	-0.52***	-0.65***	-0.52***
	(0.008)	(0.007)	(0.071)	(0.033)	(0.014)
Age 16-17 dummy	-0.81***	-1.23	-1.21***	-0.96***	-1.30***
	(0.019)	(0.021)	(0.155)	(0.043)	(0.036)
Age 18-24 dummy	-0.35***	-0.44***	-0.53***	-0.54***	-0.29***
	(0.004)	(0.005)	(0.039)	(0.017)	(0.008)
Age 35-44 dummy	0.24***	0.29***	0.28***	0.10***	0.15***
	(0.003)	(0.004)	(0.034)	(0.017)	(0.006)
Age 45+ dummy	0.28***	0.35***	0.35***	0.13***	0.16***
	(0.003)	(0.004)	(0.032)	(0.016)	(0.006)
1-4 yrs. grade school dummy	-0.34***	-0.46***	-0.28***	-0.30***	-0.22***
	(0.006)	(0.006)	(0.100)	(0.025)	(0.009)
1-4 yrs. high school dummy	0.20***	0.27***	0.33***	0.30***	0.20***
	(0.003)	(0.003)	(0.028)	(0.017)	(0.005)
1+ yrs. college dummy	0.47***	0.55***	0.54***	0.52***	0.38***
	(0.004)	(0.004)	(0.038)	(0.021)	(0.007)
Industry dummies	YES	NO	NO	NO	YES
Interaction terms	YES	YES	YES	YES	YES
Observations	207,436	207,436	3,456	14,403	88,071
Adjusted R-squared	0.50	0.37	0.31	0.26	0.35

Notes: Robust standard errors in brackets; * significant at 10%, ** significant at 5%, *** significant at 1%.
Reference category: male worker, aged 25 to 34, 5 to 8 years of grade school.

Table D3 above provides a summary of the relative compensation in 1915, 1940 and 1950. The log of total compensation is regressed against a set of dummies for gender, age and education. We controlled for the full range of industries in our sample and included a set of interactions terms between gender and our main explanatory variables. We included samples from 1940 and 1950 for the whole of the US as well as the state of Iowa, which, as before, are derived from the IPUMS dataset by Ruggles et al. (2010). The 1915 data is taken from the Iowa State Census Project by Goldin and Katz (2010).

A drawback of the 1915 Iowa data is that Goldin and Katz do not report the industry in which the worker was active. Consequently, as relative compensation by industry is unavailable in the 1915 data, we are unable to fully capture the effects of the reallocation of labour between these industries. This reallocation effect turns out to have had a significant impact on overall labour-quality growth between 1900 and 1950, as we will show below. In addition, the sole reliance on income data from Iowa introduces a bias in the compensation estimates, as wages for the different categories were not uniform across all states. Iowa may not be the most representative state for this sensitivity check, but unfortunately it is the only source of micro-data on labour income we have prior to 1940.

To tackle these issues, we include the results from 5 separate estimations in table D3. Column (1) reports the full model that we have relied on so far, based on the 1940 data for the US as a whole, including controls for industries. We drop the industry dummies in (2) and restrict the sample to Iowa in (3). Column (4) shows the results based on the 1915 Iowa data from Golden and Katz. The coefficients from (3) can be directly compared to the estimates from (4). The other columns can be used to gauge the bias introduced by the exclusion of industry specific compensation figures and the sole reliance on data from Iowa. The final column (5) shows the regression based on 1950 census data for the US as a whole. This regression includes a full set of industry dummies and interaction terms and can be directly compared against the results in column (1).

Looking first at columns (3) and (4), table D3 shows that the gap between male and female wages in Iowa was significantly bigger in 1915 than in 1940; the lower and upper 95% confidence limits for the female dummy in model (4) are -0.72 and -0.58 respectively. The estimate for the female dummy in (3) clearly falls outside these bounds. The returns to experience (proxied by age) were smaller in 1915 than 1940. The returns to education were roughly equivalent in the 1915 sample compared to the 1940 Iowa sample; the upper bounds for the high school and college coefficients in (4) are 0.33 and 0.56 respectively. Were we to base our compensation estimates on 1915 (instead of 1940), we would expect the effects on our labour quality index to be mixed. Ignoring the interaction terms, the reduced weight given to female labour in the 1915 would dampen the growth in labour quality, as we observe a sizable increase in the share of women in the labour force over the twentieth century. Similarly, the ageing of the workforce between 1900 and 1950 would show a less pronounced positive effect on labour quality growth. However, the increase in the educational attainment of the workforce during the early twentieth century should have a comparable impact when 1915 weights are used. Comparing column (5) to column (1) we would expect the effect of both gender and age on labour quality growth to be slightly higher based on the 1950 compensation weights, while the effect of education is expected to be lower. The latter can be inferred from the fact that the relative spread between the coefficient for the highest and lowest educational classes is lower based on 1950 data than for the original 1940 data.

As we will show below, of the three labour characteristics (age, gender and education) education is the driving force behind the growth in labour quality over the first half of the twentieth century. The change in educational attainment – particularly the rapid rise in the number of workers that attended high school or even college – is also the most important factor missing from Kendrick's (1961) measure of labour quality. The fact that the 1940 compensation weights allocated to the four educational classes appears to be representative for earlier years is thus reassuring. Based on identical sources, Goldin and Katz (1999: 22, 45) even show that the returns to a year of high school and college education was greater for young men and at least equal for all men in 1915 compared to 1940 when one adjusts the 1915 Iowa data to cover the national economy as a whole. This would mean the contribution of education to labour quality growth would come out even higher if we would include 1915 compensation weights into our analysis. Goldin and Katz also show that in 1950, the returns to education had indeed fallen substantially compared to the pre-war era. This, Goldin and Margo (1992: 32) say, "was primarily the result of a particular confluence of short-run events affecting the demand for labour and of institutional changes brought about by the war and the command economy that accompanied it." The post-war figures are thus less likely to approximate the relative compensation weights for the early twentieth century.

As previously noted, the 1915 Iowa data summarized in table D3 cannot be used to determine whether the 1940 relative wages by industry are relevant for earlier years, since the earlier population census does not reveal which industries the employees were engaged in. For data on pre-1940 labour compensation by industry we turn to the *National Income and Product Accounts* by the BEA (2009), which provides aggregate data from 1929 onwards. Comparing the industry-specific wages in 1929 to those derived from the 1940 census reveals that, over the course of the 1930s, relative wages by industry did not change much. The three worst-paying industries in 1940 were agriculture, personal and public services and the lumber industry. In 1929, agriculture and personal services also recorded the lowest average compensation per worker, while the lumber industry ranked as the seventh worst paying employer. The highest average annual compensation was recorded in the petroleum and coal products industry for both years. Wage data prior to 1929 is not readily available for the entire US economy, but the 1909 *Census of Manufactures* does report wages, salaries and persons employed for the major 2-digit manufacturing industries. Comparing 1909 to 1940 we observe that the textile and lumber mills consistently paid the lowest wages, while the printing and publishing, petroleum and transportation equipment industries always ranked near the top of the list of best-paying industries. This appears to suggest that the industry-specific wages observed in 1940 are a decent proxy for earlier years. The 1940-based compensation data is thus likely to adequately capture the effects of the reallocation of workers between industries on labour quality.

Decomposition

Although the coefficients from the income regression provide a rough overview of the changes of relative compensation of workers between 1915, 1940 and 1950, the effect on our labour quality estimates can only be properly observed by incorporating the new compensation matrices into our full model. We will re-estimate labour quality change between 1900 and 1950 for the private domestic economy based on the compensation weights derived on the basis of estimations (2) through (5) in table D3 and compare them to our baseline estimate from column (1). To fully assess the impact of the different compensation weights – both for the development of labour input as well as aggregate production – we should decompose the labour quality index into its underlying constituents. Jorgenson et al. (1999, p. 239) suggest a breakdown of the index on the basis of its distinctive characteristics. They propose the construction of partial indices of labour input in which only a subset of the characteristics is incorporated. To construct such a partial index, we sum the hours worked and the corresponding value shares over some of the characteristics and construct a translog index over the remaining characteristics.

Previously, we used a single subscript *l* to represent the categories of labour input cross-classified by all characteristics except for industry. Below we use a separate subscript for each of the individual characteristics: two sexes, represented by the subscript *s*; five age-groups, represented by *a*; four educational classes, represented by *e*; and thirty-eight industries, still represented by *j*. An example of the partial labour input index for gender is given below.

$$\hat{L}_s = \sum_{s=1}^{2} \mu_s \sum_{a=1}^{5} \sum_{e=1}^{4} \sum_{j=1}^{38} \hat{H}_{s,a,e,j} \qquad \text{(D.7)}$$

Equation (D.7) is based on equation (D.1), the basic labour input equation introduced in this appendix. However, now the compensation shares $\bar{v}_s$ solely distinguish between the two gender categories and is multiplied by the log change in male and female workers respectively. The resulting partial labour input index only reflects changes in the relative share of men and women in the workforce and ignores the effects of the other characteristics. As before, labour-quality growth can still be derived as the difference between the growth rates of the compensation-weighted, partial index of labour input and hours worked.

Partial indices for all four characteristics can be computed, which are referred to as first-order indices. In addition to these first-order indices, second-order indices of labour input can also be defined. These depend on any two characteristics of labour input, by adding hours of work and the corresponding value shares over other characteristics and again constructing a translog index (Jorgenson et al. 1999, p. 270). Similarly, we can define third- and fourth-order indices. In our full model, there are six second-order indices, four third-order indices and one fourth-order index. The fourth-order index reflects compositional shifts among all characteristics, as in equation (D.1).

The first row in table D4 reports the results from the decomposition of labour-quality growth for the American labour force based on the full US sample for 1940, including controls for industries. The first column in this table displays the annual average log growth over the entire period, while the subsequent columns report the partial, first order indices for education (*e*), age (*a*), gender (*s*) and industry (*j*) respectively. The final column reports the sum of the residual; i.e. second-, third- and fourth-order effects. The other rows in table D4 report the decomposition of labour quality growth based on the four remaining compensation estimates introduced in table D3.

Table D4. *Contribution to Labour Quality Growth for the Private Domestic Economy, United States, 1900-1950, in percent per annum.*

		Total	Educ. (*e*)	Age (*a*)	Gender (*s*)	Industry (*j*)	Resid.
US 1940	(1)	0.83	0.41	0.15	-0.12	0.48	-0.09
US 1940	(2)	0.52	0.38	0.19	-0.14	…	0.10
Iowa 1940	(3)	0.47	0.33	0.20	-0.16	…	0.10
Iowa 1915	(4)	0.35	0.28	0.15	-0.15	…	0.08
US 1950	(5)	0.69	0.34	0.13	-0.12	0.37	-0.04

Note: May not sum to total due to rounding. Educ. = Education. Resid. = Residual.
Sources: see text.

The first row in table D4 shows that the growth of labour quality, at the total economy level, appeared to be driven primarily by the change in educational attainment and shifts in the industrial structure. The contribution of education was positive for all decades and showed a rising trend over time, reflecting the findings by Goldin and Katz (2008). The relocation of labour from low-skill/low-productive sectors (e.g. agriculture) to high-skill sectors (e.g. trade and FIRE), reflected an improvement in the utilization of the workforce, greatly raising the potential output per worker. To a lesser extent, the gradual rise in the experience level of the American workforce, as illustrated by the increase in the average age, also positively contributed to labour-quality growth. In contrast, the rising share of women in the labour force tended to depress the growth of labour quality. Particularly the period between 1940 and 1950 – as a result of the war effort – observed a marked increase in the number of female workers.

The results from estimation (2) – where the variations in income between industries are no longer taken into account – shows a marked drop in the annual average growth of labour quality. The reallocation of workers between industries contributed a little over 0.30% per annum to labour quality growth. Note that the contributions of the remaining first order indices changes slightly as well, as the variations in income among individuals is now attributed to these categories instead of to the differences in compensation between industries (see table D3). If we narrow the 1940 sample in (3) to include compensation figures from Iowa only, we again observe a modest downward adjustment of 0.05%. Compared to (2), the difference in annual labour quality growth appears to come from a lower contribution of education as a result of the reduced returns to education we observed for (3) in table D3.

The penultimate row in table D4 reports the results based on the 1915 Iowa sample. If we compare the estimates from (4) directly to (3), we see that using the earlier weights would lower labour quality growth by about 0.12% per annum. Half of this difference comes from a reduced contribution of education and half from a lower contribution of work experience. Taking the bias for the Iowa sample and the mismeasurement of the reallocation of labour into account – observed in estimations (3) and (2) respectively – we would expect the average labour quality growth for the private domestic economy to be approximately 0.70% per annum based on the 1915 compensation weights. The labour quality estimates for the individual industries based on the 1915 income regression appear to be very similar to our baseline findings as well. The correlation between the labour quality estimates based on (1) and (4) for the disaggregate industries measured for each decade individually is a strong 0.97.

The findings on the basis of the 1950 compensation weights in estimation (5) paint a strikingly similar picture. Overall labour quality growth is reduced by 0.14% per annum compared to our original estimates in the first row of table D4. Again, the difference stems primarily from a reduced contribution of education and a lower reallocation effect (*j*). Based on the 1950 compensation data, annual labour quality growth is still approximately 0.70%. Once again, the correlation between the labour quality estimates for the individual industries based on (1) and (5) is very high: 0.98.

Overall, the modest difference between the labour quality results at the total economy level based on the 1915, 1950 and the original 1940 weights of approximately 0.12-0.14% per annum shows that our results are quite robust. This conclusion is reinforced by the striking similarity between the disaggregate results based on the two sets of weights. The benefits of the detailed 1940 estimate, that not only covers the income differences for the full US sample but can also take the reallocation effects of the shift in employment between industries into account, outweighs the need to incorporate changes in the relative incomes over time into the analysis. We prefer the 1940 weights over the 1950 weights as the latter falls outside the period we study in this paper. The post-war figures are also less likely to capture the relative compensation between the labour categories for the early twentieth century, particularly in the case of the educational classes.

Table D5. *Growth in Labour Quality by Industry, United States, 1899-1941.*

Industry	Growth in labour quality (percent per annum)				
	1899-1909	1909-1919	1919-1929	1929-1941	1899-1941
Farming	0.00	0.73	0.31	0.48	0.38
Metals	0.16	0.54	0.54	0.44	0.42
Anthracite Coal	0.19	0.49	0.56	0.51	0.44
Bituminous Coal	0.19	0.49	0.56	0.51	0.44
Oil and Gas	-0.05	-0.22	0.73	0.65	0.30
Non-metals	0.13	0.55	0.14	0.54	0.35
Foods*	0.06	-0.06	0.26	0.41	0.18
Tobacco	-0.38	0.10	0.20	0.65	0.17
Textiles	0.52	0.67	0.66	0.71	0.64
Apparel	0.24	0.63	0.40	0.06	0.32
Leather Products	-0.71	0.23	0.26	0.31	0.04
Lumber Products	-0.06	0.47	0.46	0.45	0.33
Paper	0.93	0.63	0.67	0.60	0.70
Printing Publishing	0.07	0.42	0.39	0.47	0.34
Chemicals	-0.09	0.51	0.43	0.62	0.38
Petroleum, Coal Products	0.19	0.61	0.50	0.84	0.55
Rubber Products	0.48	0.75	0.56	0.76	0.65
Stone, clay, glass	-0.03	0.37	0.57	0.44	0.34
Primary Metals	0.05	0.57	0.61	0.47	0.43
Fabricated Metals	-0.02	0.45	0.56	0.42	0.35
Machinery Non-Electric	0.02	0.40	0.75	0.54	0.43
Electric Machinery	0.84	0.48	0.51	0.51	0.58
Transport Equipment	-0.20	0.15	0.60	0.60	0.30
Furniture	-0.36	0.45	0.23	0.32	0.17
Miscellaneous	0.00	0.44	0.71	0.43	0.40
Electric Utilities	0.13	0.39	0.40	0.98	0.50
Manufactured Gas	-0.19	0.14	0.45	0.71	0.30
Natural Gas	-0.19	0.14	0.45	0.71	0.30
Construction*	-0.14	0.49	0.15	0.13	0.16
Wholesale & retail trade*	-0.04	0.40	0.19	0.09	0.16
Railroads	-0.08	0.53	0.75	0.76	0.50
Local Transit	0.14	0.60	0.60	0.57	0.48
Residual Transport	0.14	0.12	0.55	0.49	0.33
Telephone	0.18	0.00	0.80	1.14	0.56
Telegraph	-0.06	0.17	-0.19	0.84	0.22
Post Office*	0.30	0.35	0.46	0.44	0.39
FIRE*	-0.36	-0.25	0.41	0.54	0.11
Spectator Entertainment*	0.21	0.77	0.30	0.24	0.37
Manufacturing	0.21	0.71	0.56	0.43	0.47
Great inventions*	0.25	0.62	0.29	0.24	0.35
Aggregate measured sectors	0.99	1.09	0.81	0.75	0.90
PDE	0.85	1.12	0.65	0.59	0.79
Memorandum:					
Kendrick PDE	0.50	0.41	0.17	0.20	0.32
Minimum	-0.71	-0.22	-0.19	0.06	0.04
Maximum	0.93	0.99	0.80	1.14	0.70
Range	1.64	1.20	0.98	1.08	0.67

Notes: * = sector measured in this paper but not by Kendrick.
Source: own calculation, see text and Appendix D. Average annual growth rates calculated using continuous compounding.

Appendix E. Dual TFP

So far, we have relied on a conventional or 'primal' definition of TFP, where the rate of TFP growth is defined as the difference between the growth of real output and the weighted average growth of real physical and human capital. For 1929-1941, the growth of real factor input is given by the change in the flow of respectively capital- and labour services, both weighted by their respective factor shares in the total value of output.[29] The intuition behind the calculation of primal TFP is that real output growth not covered by the growth in real factor input represents a shift in the production function resulting from productivity advances, efficiency change or, potentially, measurement error (Solow 1957).

Griliches and Jorgenson (1967) demonstrate that TFP can also be computed from indices of prices for output and input, instead of quantities. The reasoning behind this 'dual' approach to productivity change is very similar to that of primal TFP: any price reduction for output not resulting from the (weighted) change in nominal wages or the rental price of capital represents a shift in the production function. Griliches and Jorgenson show that under the same assumptions – e.g. constant returns to scale and perfect competition – the primal and dual approaches will yield identical results. Even if these assumptions were to be violated, however, Antràs and Voth (2003: 57) show that primal and dual estimates of TFP would be biased to the same degree, as both measures are theoretically equivalent. The frequently observed differences between estimates for the primal and dual approach are more likely the result of inconsistencies in how prices and quantities are measured in the national accounts or the use of a different production function or disparate factor shares (see Hsieh 2002; Aiyar and Dalgaard 2005).

For the period 1929-1941 we have all the building blocks required to estimate dual TFP. Denoting TFP by *A*, the dual growth accounting identity is given by:

$$\widehat{A} = \alpha\widehat{p}_K + (1 - \alpha)\widehat{p}_L - \widehat{p}_Y \tag{E.1}$$

where hats indicate growth rates in natural logs, *p* the price for capital (*K*), labour (*L*) and output (*Y*) and α the factor share of capital.

The prices in equation (E.1) are derived implicitly from the inputs for the primal TFP estimates, as described in the main text and appendices C and D. The growth of output prices ($\hat{p}_Y$) is estimated as the residual of nominal- and real value-added growth at both the sector and the industry levels.

We adopt the definition by the BLS (2014) for nominal labour income, i.e. the sum of compensation to employees (COMP) and a portion of noncorporate income (INC).[30] Note that both compensation and noncorporate income are directly available from the NIPA for 1929-1941; see table C1. From the growth in nominal labour income, we deduct the growth in total persons engaged in production (PEP), the average hours of work for employees and labour quality to obtain the growth of the price of labour ($\hat{p}_L$). Persons engaged is listed in the NIPA, average hours of work are taken from the HSUS (1975) and Kendrick (1961), and the construction of labour quality is described in detail in appendix D.

As discussed in appendix C, the rental price of capital assets depends on the rate of depreciation, the (industry) rate of return and any capital gains or losses from price changes in the price of capital assets; see equation (C.6). To arrive at the average growth rate of the price of capital by industry ($\hat{p}_K$), we weighted the rental price for capital assets by that asset's share in total capital compensation; see equation (C.5).

[29] Prior to 1929, for the capital input we rely on the growth rate of the stock of capital instead.

[30] The portion of noncorporate income allocated to labour income is the sum of proprietors' income (PROINC) and farm income (FRMINC) times the ratio of compensation (COMP) and nominal value added minus total noncorporate income.

The factor share of capital (α) is calculated as the average price of capital assets times the total stock, which is identical to gross operating surplus (GOS) minus the sum of noncorporate income not allocated to labour. Note that the factor-share of capital used in the dual approach deviates from that used previously for primal TFP. The factor shares taken from Kendrick (1961), used throughout this paper to retain consistency with Kendrick's original estimates as well as between the different periods, allocate greater weight to labour.[31] Still, as the growth of the price of labour and capital is reasonably similar for the period 1929-1941 (0.7 and 1.2% p.a. respectively), the factor shares only modestly impact the estimate of dual TFP.

Table E1 compares the results for the dual TFP estimates to their primal counterparts for the years 1929-1941, as well as for 1948-1960 and 1960-1973. The post-war growth rates are taken directly from the Bureau of Labor Statistics' (2014) Multifactor Productivity Measures.

Table E1. *Average Annual Rates of Growth of TFP, United States, 1929-1973, percent per annum*.

	Primal	Dual
Private domestic economy (PDE)		
1929-1941	1.86	1.82
1948-1960	1.98	1.87
1960-1973	2.21	2.25
Private domestic nonfarm economy (PNE)		
1929-1941	1.93	1.89
1948-1960	1.68	1.59
1960-1973	1.99	2.02

Sources: primal TFP see tables 5 and 7; dual TFP, 19291941: see appendices C and D; 1948-1973: and Bureau of Labor Statistics, "Historical Multifactor Productivity Measures", http://www.bls.gov/mfp/home.htm (October 2014).

Table E1 shows that for pre- and post-war periods, primal and dual TFP estimates were very similar. For the private domestic economy, dual TFP was still a very strong 1.82% growth p.a. during 1929-1941, but not as strong as during the 1960s which showed productivity increases at 2.25% p.a. Overall, the dual TFP estimates bolster our finding that the 1930s was not the most technologically progressive decade of the century, as claimed by Field (2011, 2013).

[31] Kendrick (1961: 285) allocates a 23 percent share to capital for the PDE, whereas the method described for the dual approach estimates this share at 37 percent.

Appendix F: Research and Development inputs by industry

The purpose of this appendix is to show how our new sectoral TFP growth data can be linked to sectoral data on R&D inputs to explore whether or not there is a clear link between R&D inputs and TFP growth, as some authors suggest (Bloom et al. 2017). The data on R&D inputs is derived from the National Research Council survey data on R&D in manufacturing as reported by Mowery and Rosenberg (1989), based on Mowery (1981). The data consists of laboratory foundations per decade, the number of research scientists and the number of research scientists per 1,000 of all wage earners. For the R&D laboratory foundations data, our sector Miscellaneous is matched with the category 'Instruments' and with the miscellaneous laboratories from the survey data. The latter have been computed by subtracting the sectoral total from the grand total. The cumulative foundations of new laboratories from 'prior to 1899' through 1918 is what is reported Table F1; data on laboratories subsequently closed is not available. For the number of research scientists, Mowery and Rosenberg (1989) report that the miscellaneous category is not available, and in this instance only Instruments have been used to match with our Miscellaneous sector.

At the disaggregated level, comparing R&D indicators for manufacturing industries with TFP growth shows a weak relationship, with limited correlation in some instances but none in others. A simple visual inspection of several R&D indicators (Table F1), shows that the ratio of TFP growth acceleration over R&D inputs differed sharply by industry, making it unlikely that R&D came anywhere close to dominating TFP growth. Simple coefficients of rank order correlation for R&D indicators with various accelerations in TFP growth run from 0.15 to 0.61, suggesting some influence of R&D but not a lot (Table F2).

Table F1. *R&D inputs and TFP Growth Acceleration in U.S. manufacturing industries, 1919-1929.*

	R&D labs founded pre-1919 (%)	Share of scientists in 1921 (%)	Scientist intensity in 1921 (average)	Growth scientists 1921-27 (% p.a.)	Growth intensity 1921-27 (% p.a.)	TFP growth acceleration (%-pt p.a.)
Foods	9	4	0.3	19	17	5.1
Tobacco	0	0	0.0			1.0
Textiles	3	1	0.0	28	26	1.8
Apparel	0	0	0.0			2.2
Leather Products	1	1	0.2	6	3	2.2
Lumber Products	0	1	0.1	9	22	3.1
Paper	4	3	0.9	13	10	3.3
Printing Publishing	0	0	0.0			0.2
Chemicals	28	40	9.3	8	4	7.0
Petroleum, Coal Products	3	6	3.3	18	16	8.3
Rubber Products	3	7	3.6	9	4	2.8
Stone, clay, glass	6	3	0.7	24	19	3.8
Primary Metals	9	11	1.4	10	3	4.1
Fabricated Metals	6	4	0.5	20	14	2.2
Machinery NonElectric	10	5	0.4	20	16	1.5
Electric Machinery	9	7	2.0	22	16	3.1
Transport Equipment	3	3	0.4	19	16	3.7
Furniture	0	0	0.0			4.6
Miscellaneous	5	5	0.7	13	8	4.0
Total	100	100	1.0	14	7	3.7
Coefficient of variation	1.19	1.64	1.73	0.41	0.54	0.57

Notes: The TFP-growth acceleration has been calculated by subtracting the growth rate for 1899-1919 from the growth rate of 1919-1941. Share of scientists has been calculated from the absolute numbers and total reported for 1921 by Mowery and Rosenberg (1989), p. 64. R&D labs founded and scientist data exclude independent research laboratories, whose scientists numbered 15.2% of all research scientists in manufacturing in 1921. Scientist intensity = the number of research scientists per 1,000 of all wage earners.

Sources: Mowery and Rosenberg (1989); Bakker, Crafts and Woltjer (2017).

Table F2. *Correlation between R&D inputs and TFP growth indicators in U.S. manufacturing, 1919-1929.*

	TFP growth acceleration	IGC	IGC/VA (TFP growth)
Share R&D Labs foundations before 1919	0.49	0.31	0.29
Share of scientists in 1921	0.55	0.24	0.44
Scientist intensity in 1921	0.61	0.15	0.58
Growth of			
Scientists, 1921-1927	-0.16	0.15	-0.11
Scientist intensity, 1921-1927	-0.17	0.04	-0.33

Notes: The TFP-growth acceleration has been calculated by subtracting the growth rate for 1899-1919 from the growth rate of 1919-1941. R&D labs founded and scientist data exclude independent research laboratories, whose scientists numbered 15.2% of all research scientists in manufacturing in 1921. Scientist intensity = the number of research scientists per 1,000 of all wage earners.
IGC = intensive growth contribution, share of total; VA = share in total value added.
Sources: Mowery and Rosenberg (1989); Bakker, Crafts and Woltjer (2017).

Lorenz curves plotting the two key indicators and the IGC show the same picture (Figure F1, panels A and B). If there would be a clear one-to-one relationship between R&D indicators and the IGC, one would expect the Lorenz curves to be close to the diagonal. In practice, they are very far away from that line, showing that the effect of R&D was extremely variable: if we look at the share of intensive growth contribution (IGC) over the share in research scientists employed in 1921 per industry (the cumulative of which is the Lorenz curve's tangent), the range covers two orders of magnitude, or more than fortyfold, from 0.2 in Chemicals to 7.7 in Textiles. The IGC over R&D labs founded before 1919 ranges over three orders of magnitude across industries, or more than a hundredfold, from 0.3 in Chemicals to 29.3 in Apparel. If TFP-growth was largely driven by R&D outlays, we would not expect to see these large differences between R&D and IGC across industries. Likewise, the five industries with no R&D Labs whatsoever before 1919, accounted for 18% of the IGC in the 1920s, and obversely, industries accounting for 50% of R&D labs founded before 1919 accounted for just 16% of the IGC in the 1920s.

The big differences are reflected in the 1920s TFP growth acceleration over research intensity, as the highest ratio (Textiles) was ninety times the lowest (Chemicals). The three sectors growing fastest in research intensity between 1921-1927 (Textiles; Stone, clay, glass; Electric Machinery) accounted for 3.7% of value added and 10.7% of the IGC in the 1920s, and 3.8% vs. 22.9% in the 1930s. An OLS regression on the log growth acceleration of TFP for the 1920s on the log of research intensity in 1921 suggests that increasing research intensity by one percent near the mean of one scientist per 2,000 wage earners, would increase TFP growth acceleration by a little under 0.2 percentage points (Figure 1 in the main text). Yet the same exercises for the 1930s yield negative coefficients and using other R&D indicators yields even less robust relationships.

A special case is chemicals, which was by far the most R&D intensive industry. One reason for this might be the discovery of the periodic table in the 1860s, which sharply decreased the costs of the R&D needed to reach a given quality level and provided a clear 'roadmap' for future research efforts. Chemicals accounted for almost 30% of labs founded before 1919, 40% of all research scientists employed in 1921, and 20% of additional scientists hired until 1927, but for only 7% of TFP growth in the 1920s and 5% in the 1930s. While Chemicals had the second-highest TFP growth acceleration in the 1920s, it had the third-lowest in the 1930s. This underperformance surprises all the more because other evidence also suggests chemical R&D became extremely well-developed, especially by absorbing knowledge from abroad: it obtained various patents

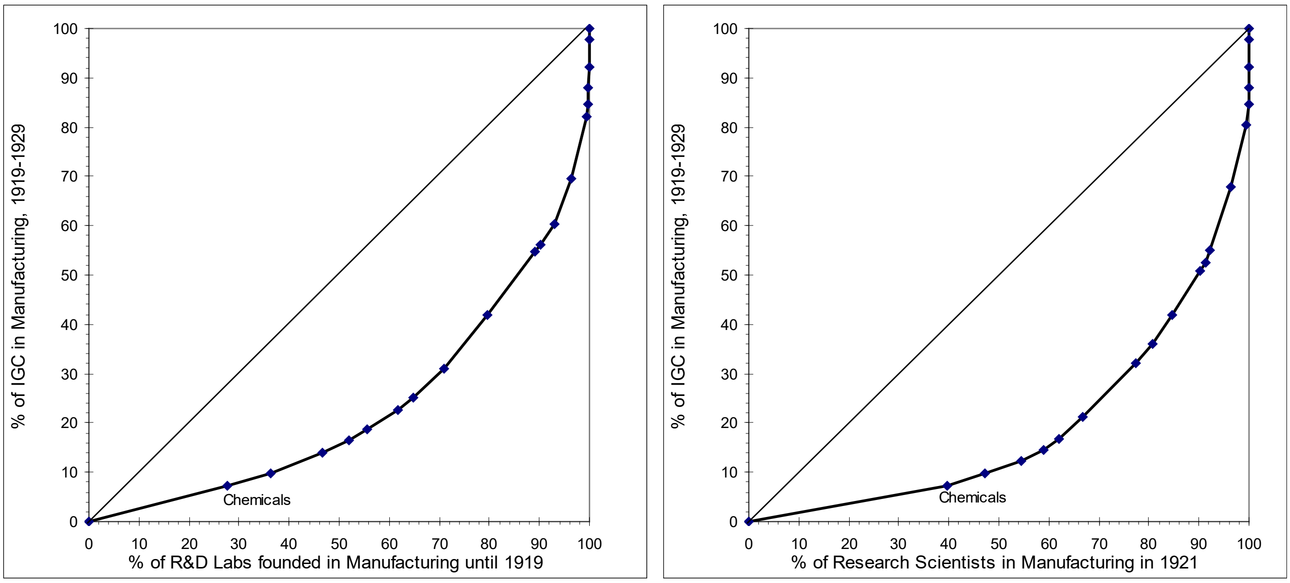

Figure F1. Panels A and B. *Lorenz curves for the share of R&D Labs founded before 1919, the share of research scientists in 1921, versus intensive growth contribution, for US manufacturing sectors, 1919-1929.*

Source: National Research Council surveys on R&D in Manufacturing, reported by Mowery and Rosenberg (1989); Table 2 of this paper.

through wartime expropriations (Moser and Voena, 2012), and patent acquisition continued throughout the 1920s. Standard Oil of New Jersey even licensed the entire oil patent portfolio of IG Farben, the German chemicals cartel, for an amount equal to about 30% of total U.S. industrial R&D outlays in 1930 (Bakker, 2013: 1801-2; Enos, 1962). During the 1930s, many top German scientists fled to the United States, generating quantifiable knowledge spillovers (Moser et al., 2014). Clearly, if R&D was driving TFP-growth one would expect Chemicals to have had a much higher IGC.

The survey data used as the source here is of course not perfect and one should take into account the following qualifications. Independent research labs are not taken into account, and in 1921 15.2% of research scientists in industry worked in independent R&D labs, declining to 8.7% by 1940 (Mowery and Rosenberg 1989). This means that some of the growth in some industries may not reflect an increase in R&D but also partially a substitution from external to internal R&D. Noise might also be caused by whether all those research scientists really only worked in R&D. Edgerton (1996) writes that in industry most scientists are employed outside of R&D. According to the source, what is counted are scientists employed in R&D, but we do not know to what extent they were also used in day to day management of the manufacturing process especially in industries such as Chemicals and Petroleum. This fraction may differ by industry. Some noise might also be caused by the circumstance that only a very minor part of R&D is generally is Research such as inventions and innovations; the overwhelming majority of research scientists in industry were employed in Development (Edgerton 1996).

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